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LONG-RANGE SEARCH SONAR SYMPOSIUM OF SEPTEMBER 5, 1951

NAVAL RESEARCH LABORATORY

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NRL REPORT 3919

LONG-RANGE SEARCH SONAR SYMPOSIUM OF SEPTEMBER 5, 1951

H. L. Saxton, R. J. Urick, T. E. Bayston,
and M. S. Wilson

November 28, 1951

NAVAL RESEARCH LABORATORY
CAPTAIN F. R. FURTH, USN, DIRECTOR
WASHINGTON, D.C.

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PREFACE

The Long-Range Search Sonar Problem is aimed at providing answers to the many questions within the Navy regarding long-range-search possibilities using echo-ranging. A submarine, the USS GUAVINA, was selected (in full discussions with CNO) as a sonar platform for a 10-kc equipment. A submarine was selected because it provided features of platform stability and depth control which seemed highly desirable in an experimental field installation. After two 6-week operating periods in the Key West area, our lack of ability to draw conclusions concerning deep-water operation was glaringly apparent and every effort was bent toward arranging a trip to Guantanamo with operations in deep water. Through the cooperation of ComOpDevFor and others, such arrangements were made for the third operating period. At the conclusion of this third period, we were prepared to report problem status to those in the U.S. Navy most concerned with active search sonar possibilities. Accordingly, the presentation reported herein was made before some 40 interested representatives of offices and bureaus concerned with the problem.

H. L. Saxton
Chairman

CONTENTS

WELCOMING REMARKS
Captain F. R. Furth, Director, Naval Research Laboratory

Rear Admiral Bolster, Rear Admiral Akers, Gentlemen:

We're delighted with the opportunity to present to you this morning some of the most recent developments in our Long-Range Underwater-Sound Echo-Ranging Program. We particularly welcome this opportunity to inform you of these latest developments and also to acquaint you with our needs for additional ship's services to carry on the work which we have started and have been carrying on actually for some two years now. Two rather startling developments have occurred recently. One has to do with the measurement of target strength at the low frequencies and the other has to do with cross-correlation and improving the signal-to-noise ratios. The details on these two new developments will be given to you later on in the presentation. I also welcome this opportunity to express my appreciation on behalf of the laboratory to the Bureaus and to the Office of Chief of Naval Operations, and to, of course, our parent office, ONR, for the complete support which they have given us in this particular program.

The long-range-sonar research started out with very little to go on except the use of parameters which were developed during the war, prior to the war, and immediately after the war and from those parameters it was hard to visualize just what we might be able to accomplish in low-frequency echo-ranging. However, there was sufficient evidence from the theoretical studies to give us hope for considerable improvement. We were not looking for a matter of small percentage improvement in the values of ranges obtained by World War II equipment; we were looking for several times these ranges. We were interested in getting really out to long ranges. It was only by the support of the bureaus and the officers that we were able to conduct this work, and it is gratifying to report that we have had some considerable successes.

REVIEW OF PROPAGATION PATHS OVER LONG RANGES

Dr. H. L. Saxton, Superintendent of Sound Division

Our effort in long-range search has been stated as aimed at finding acoustic paths and designing equipment to exploit them. We never undertook to punch our way into shadow zones by brute force. Efforts in this direction could only result in incremental improvements, while we were after an order of magnitude. From time to time persons, including myself, have stated that when a 10-fold increase in range has been achieved, we shall be over the hump, and that further increases will be relatively easy. This still holds.

This Laboratory has studied propagation in surface-bounded ducts and over paths which include a bottom reflection -- in both cases to ranges of 28 miles. The use of pulse transmission was found mandatory. These paths are shown in Figure 1. The use of such long ranges has enabled accurate determination of divergence loss and attenuation in the 5 to 10-kc frequency band. Via the bottom in deep water, the loss is that of spherical divergence plus an absorption, the absorption coefficient being $.01f^2$. In surface-bounded ducts the loss after the first 1000 yards is approximately that of cylindrical divergence plus attenuation, this attenuation consisting of an absorption, α_0, plus a leakage term, α_L, value of which depends upon sea conditions, layer depth, and frequency. The nature of the dependence was presented and explained by Mr. Urick in the Second U.S. Navy Symposium on Underwater Acoustics last fall (1950).

The loss found by both paths was very appreciably less than predicted and anticipated from previous data, and is sufficiently consistent to permit confidence in range predictions over either path.

The surface-bounded duct is a phenomenon of common occurrence, arising from a mixed surface layer. If the transducer and the target are both contained in this duct, it will permit long ranges. With the present equipment, ranges up to 25 kiloyards have been obtained. There are two objections to depending upon this duct. First, it is variable in quality sometimes vanishing altogether, and second, an enemy submarine may escape detection by diving below the duct.

The use of bottom reflection provides an alternative path which can be depended upon all the year around in some areas, since it is not subject to variations with sea state and atmospheric conditions. Furthermore, it is a path to a target at any depth. Ranges out to 15 kiloyards should be reasonably dependable with present experimental equipment, and no limitation of maximum range is known other than the limits of the reasonably flat-bottomed portions of the oceans. It suffers the possible deficiency of introducing a skip distance inside an annular ring of coverage.

Assuming the use of bottom reflection with 10-kc equipment, and also assuming no reflection loss, the values of propagation loss are given for depths of 900, 1800 and 2700 fathoms tabulated in the first column of Figure 2. Assumed tilts of 15°, 25° and 25° respectively for the three depths appear in the second column. From these depths and tilts, the horizontal ranges and propagation losses have been computed from the formula of Figure 2 for frequencies of 10 kc and 7 kc. For the moment, let us simply make a mental note that the losses listed, which will be used later, have been computed from an experimentally verified formula.

The over-all loss from the level of pulse transmission to the level of echo reception will include bottom-reflection loss and target strength. NRL has recently acquired, by utilization of its experimental 10-kc search equipment in the USS GUAVINA, experimental data which indicate a reflection loss and additional data which permit calculation of target strength. The results are important enough to warrant a description of the experimental procedure and a discussion of the data which will now be presented by Mr. R. J. Urick, Head of the Propagation Branch of the Sound Division.

DISCUSSION

Rear Admiral Akers: What happens at shallower depths?

Dr. Saxton: At shallower depths, propagation via the bottom should be even better. We could insonify the whole range of depth from surface to bottom. In that case, the energy would be reflected back and forth assuming a good reflecting bottom, and it would be channeled or confined out to very long ranges. The nearer the beam comes to being tangent to the bottom, the better its reflection.

MEASUREMENTS OVER LONG RANGES WITH PRESENT EXPERIMENTAL EQUIPMENT AND TARGET-STRENGTH MEASUREMENTS

R. J. Urick, Propagation Branch

It seemed to us about two or three months ago that the time had come when we must attempt some actual quantitative measurements with the equipment installed in the GUAVINA.

There are obviously two ways to go about this. One is to use an actual live submarine and obtain echoes from this submarine at long ranges. However, in many respects this is unsatisfactory. It involves submarine time; furthermore, the submarine itself is of unknown target strength which may or may not vary with aspect. We therefore set about finding a method which would obviate temporarily the need for a submarine and at the same time be able to give us some quantitative information on a fictitious target of known strength for use in prediction.

The method employed involved a surface ship and two hydrophones as shown in Figure 3. On the left is a highly symbolic picture of the USS GUAVINA with its transducer mounted topside and forward; on the right is the surface ship escort, which in our particular case, was the USS ALBATROSS (AMS-1). From it were suspended two transducers. One of these was a projector which sent out a constant-intensity ping. The other was a hydrophone which recorded the ping sent out from the projector, and also the incoming echo-ranging ping from the GUAVINA. With the recording equipment on the ALBATROSS, this setup measured the apparent target strength of the repeated ping sent back from the projector on the ALBATROSS. The repeated ping was measured also with the recording equipment installed on the GUAVINA. The two paths discussed by Dr. Saxton are shown, and measurements and echoes were obtained by way of these two paths. The first path utilized is with horizontal tilt of the GUAVINA's projector; the second is realized by a tilt that varied between 20° and 30° downward, depending upon the water depth and the range. With horizontal tilt, closing runs were made from a range of between 20 and 25 kiloyards. By closing run, I mean a recording of all echoes reaching the GUAVINA as the GUAVINA approached the ALBATROSS.

The results of one of the horizontal tilt closing runs is shown in Figure 4. On the top is plotted signal level in db against range from zero out to 26 kiloyards. Each plotted point is the average of 10 pings during the approach run. The line in this case is a computed curve which shows the loss mentioned by Dr. Saxton, namely, cylindrical spreading beyond approximately 1000 yards plus an additional loss due to absorption and leakage. The absorption value used here was 1 db per kiloyard at 10 kc; the leakage value was found, by adjustment, to be 0.3 db per kiloyard. (Of course, we have no good way of determining the leakage a priori, although we do know certain semiquantitative things about it.) The total loss, in addition to divergence, is thus 1.3 db per kiloyard, which fits well with the data. Similarly we can plot apparent target strength for the constant-intensity echo repeater and fit the data with a curve of the same type. Again the fit is good. The principal objective is to determine the echo levels from a target having a target strength of some constant value. This value was taken to be 30 db target strength. The lowest plot shows the data of the upper two plots corrected to 30 db, and at the base are shown the observed noise levels at speeds of 2 and 6 knots. At a range of 22,000 yards, it will be seen that the corrected echo levels are 10 or 12 db above the noise level at 2 knots.

In addition to obtaining these fictitious echoes of known target strength with horizontal tilt, we also obtained echoes by way of the bottom. It would be well at this point to show some examples of the records that were obtained. Figure 5 shows two pairs of records obtained at 30° tilt, the upper pair at 15,600 yards and the lower pair at 600 yards. The top record of each pair was obtained on the GUAVINA. The bottom record was obtained on the ALBATROSS to determine the equivalent target strength associated with each false echo. It is important to notice that all reverberation dies out by 16,000 yards and that the echoes, marked by arrows, appear in a noise background. The two echoes arise from the two acoustic paths that exist; even though the transducer was tilted downward, we did obtain an echo by way of the surface channel. The channel was so good, and the searchlight beam so non-ideal, that the horizontally traveling echo was stronger than the bottom reflection.

Figure 6 is another record which shows three pulses. The first one (shown by an asterisk) is the reflection from the hull of the ALBATROSS. Even though the ALBATROSS is so small in size and so shallow in draft, we did at this range, 16,000 yards, and occasionally at all ranges, obtain echoes from its hull. This echo is followed by the delayed false echo and that in turn is followed by a signal put in electronically for the purpose of scale calibration. Shown below in the figure is the record obtained on the ALBATROSS.

Figure 7, in two parts, shows a record obtained on the GUAVINA. It shows successive echoes at a range of 19,000 yards with zero tilt as the GUAVINA dove below the surface layer. The repeated or false echo is indicated by the arrows. You will notice that this arrowed echo dies away as the submarine dives below the surface bounded channel. This is simply an illustration of the observation that the transmission in the surface duct seems to be best at a shallow depth.

Finally, Figure 8 again shows the effect of depth on transmission. The upper pair of records were obtained with zero tilt and the bottom pair with 25° tilt. The upper pair (at depths of 60 feet and 200 feet with zero tilt) show that the echo is markedly affected diving below the surface channel (about 120 feet in thickness.) With 25° tilt, the bottom reflection remains unaffected.

The data was obtained during July 1951 on a cruise from Guantanamo, Cuba, to Key West. We regularly obtained bottom-reflected echoes in the area south of central and western Cuba. However, we were not successful in getting bottom echoes south of Guantanamo in the Guantanamo-Santiago area. The reason for the absence of bottom-reflected echoes south of

Guantanamo is probably the irregular and steep slope of the bottom. The charts show considerable variations in water depth, in this region. We were, I think, simply not able in a given situation, to beam the searchlight accurately on a fixed target. However, in four of the five areas worked during the week's cruise, we did obtain bottom reflected signals.

Question: How did you measure those variations in depth -- with a fathometer reading, or were you measuring the stretching out of a pulse?

Mr. Urick: With the fathometer on the GUAVINA.

Question: Were you measuring gross irregularities or fine irregularities?

Mr. Urick: Just the gross irregularities in deep water. It is apparent that if the bottom has appreciable slope it will send the GUAVINA's beam away from the ALBATROSS.

When the bottom reflection was obtained, it was found that the transmission loss from 600 yards out to a long range was about $11\frac{1}{2}$ db greater than could be accounted for by spherical divergence and absorption. This apparent reflection loss at the bottom is in contrast to our expectations based on measurements on previous field trips, where we found no loss at all. The source of that discrepancy is unknown, and is perhaps associated with the use of nondirectional transducers in the earlier work.

Figure 9, again with level plotted against range, summarizes the data obtained. The crosses are each an average of 10 pings by way of the surface duct, obtained with horizontal tilt. The horizontal lines show the noise background against which the echoes were obtained. (I should stress at this point that the noise background at ranges in excess of 15,000 yards was consistently self-noise rather than reverberation. Reverberations seem to die into noise at about 15,000 yards, so that we were not "reverberation-limited" at long ranges.) The dots are 10-ping averages of the bottom reflection. The plotted points have been reduced to a target strength of 30 db, that is, they are plotted to represent a target of strength 30 db. This is believed to be a good rough estimate of the 10-kc target strength from the new data to be described later. The figure shows that the echo of a submarine of strength 30 db at about 30,000 yards in the surface duct would be at the same level as the noise. By way of the bottom reflection, the echo at about 16,000 yards would be at the same level as the noise. I should stress that this figure is entirely observational, without anything of the nature of prediction or adjustment of the data in it. The bottom reflection is seen to be quite a bit below the surface channel echo in level and illustrates the apparent loss of $11\frac{1}{2}$ db at bottom reflection -- for which we have no explanation.

I would like now to describe some very recent measurements of target strength. Having this much information on the expected ranges of a synthetic target, what we would like to know next is the target strength of a typical submarine. We obtained the services of the USS CHOPPER in the Key West area for a 3-day period, and were successful in determining the target strength by a new method. The results were somewhat startling in that the average target strength turned out to be 32.7 db, which is approximately 20 db higher than the figure that has been used in estimates of performance.

Target strength is a measure of the reflecting power of a submarine, and is expressed as the ratio of the reflected intensity to the incident intensity when the reflected intensity is measured at one yard. Target strength as used in sonar is similar to the parameter used in radar (radar cross section), except for a factor of 4π. Target strength is, however, more convenient because it can be used directly in the echo-ranging equation without troublesome questions of the factor 4π.

Many measurements of target strength have been made in the past, especially during World War II. Field measurements as well as theoretical, and optical studies on models have been made. The data obtained at sea on an actual submarine at frequencies of 18 kc and above seem to show beam-on target strengths of about 25 db, decreasing to perhaps 10 db on the bow and the stern. The mathematical and optical studies do not quite agree with the field data in that lower values are found on the bow and stern; in other words, the field measurements give higher values on off-beam aspects. Since World War II, there have been, to my knowledge, two additional determinations of target strength in the field, one by Woods Hole and USNUSL jointly, and the other more recently by NEL on their experimental submarine USS BAYA.

All the field measurements seem to have been obtained by the same method which requires the accurate knowledge of the driving and receiving sensitivities of the echo-ranging equipment, plus a knowledge of the transmission loss at the time the data were obtained. This transmission loss could be obtained either by guess work or by field measurement during the target-strength measurement.

We have preferred to measure the target strength directly by a somewhat more elaborate method that requires no knowledge of the transmission loss or of the equipment calibrations. It does, however, require an installation and a recording of data on board the target submarine.

Figure 10 serves to show the essence of the method. The submarine on the left is the target submarine, the USS CHOPPER, a guppy-schnorkel submarine. The one on the right is the GUAVINA, which contains the 10-kc echo-ranging sonar, plus suitable recording gear to receive and record what comes back from the target. A special installation of two hydrophones was made on the CHOPPER. One hydrophone acted as a transponder, sending back a constant-intensity delayed ping on receipt of the ping from the GUAVINA. The other hydrophone served to receive both the ping from the GUAVINA and that from the transponder. The two hydrophones were mounted 5 feet apart as far forward as possible toward the bow of the target submarine, and both were nondirectional in the horizontal plane.

The figure shows the two pairs of idealized pulses, labeled A, B, C and D. A and B are, respectively, the echo-ranging ping from the GUAVINA as received on the CHOPPER, and the transponder ping sent out a few seconds later by one of the two hydrophones. C and D are respectively the echo from the target and the transponder ping received on the GUAVINA. The equations below indicate the basic principle of the method. The difference between the unknown target strength of the submarine and the equivalent target strength of the transponder T' is equal to the difference C-D when expressed in db. The transponder target strength T' is the difference in db between the pulse heights B-A on the record obtained on the target. Hence, the target strength is merely the sum of the two level differences between the two pairs of pulses when attention is given to sign. The second equation tacitly assumes that the two transducers are one yard apart; in our case, when they were 5 feet apart, the correction 20 log 5/3 is required. In summary, it should be clear that what is being done is to obtain from the GUAVINA record a comparison of the submarine echo with the spurious echo from the transponder and from the target-submarine record the equivalent target strength of the spurious echo.

Figure 11 is a photograph of the pair of hydrophones on the CHOPPER, mounted on a hexapod about 6 feet above the deck near the bow. This location provided the clearest all-around acoustic view from the hydrophones, with only a 10- or 15-degree sector aft obscured by the conning tower.

Figure 12 is an example of the records obtained. The top record, obtained on the CHOPPER, shows the A and B pulses. Below it are the corresponding C and D pulses obtained on the GUAVINA, plus reverberation. At the base are 1-second time ticks. Pulse-to-pulse matching was facilitated by accurate time checks and the use of manual repeat-back on the transponder to give slightly varying time intervals. On the right is shown the record scale in decibels above an arbitrary reference. The average target strength, the sum of the db differences plus the correction from 5 feet to 1 yard, comes out to be 42 db for the 10 pulses shown.

The field measurements were made during 3 operating days in August 1951 in an area off Key West, Florida, where the water depth was 100 to 400 fathoms. The GUAVINA circled the CHOPPER at about a 1000-yard range while the latter maintained a constant course at a speed of 2 knots. Eight circling runs were made with both submarines at periscope depth, and about 1000 pings were recorded and measured. The comparatively long pulse length of 100 ms provided by the 10-kc equipment was employed. Note that this pulse length was sufficient to insonify simultaneously the whole of the submarine even at bow or stern aspects.

Figure 13 shows one day's results of submarine target strength plotted against aspect for somewhat over two revolutions of the GUAVINA about the CHOPPER. Each plotted point is the target strength measured from a single ping, different symbols being used for the different times around. Several features shown here are worth mentioning. One is the apparent absence of any pronounced dependence on target aspect. Another is the unexpectedly high values of target strength, the average of the values plotted here being 36.3 db. A further feature is the high ping-to-ping variability in target strength, the values ranging from less than 20 db to over 50 db.

A clue as to the nature of this variability is provided by Figure 14 which represents the same data as the previous one, but shows the level of the submarine echo (rather than target strength) plotted against aspect. Note that the variability is less than in the target-strength plot, with again no apparent aspect variation.

All the data were obtained with horizontal tilt and represent horizontal "looks" at the target. Considerable time and effort was spent during the three days to obtain bottom reflections from the CHOPPER but without success, apparently there exists a very-high bottom-reflection loss in the Key West area, due either to absorption or to scattering by the coral rock and mud bottom in this area.

The high values of target strength and its independence of aspect angle would indicate that at 10 kc the target does not reflect appreciably in a specular manner, but that excitation and reradiation by the outer portions of the hull is involved, or perhaps reflections from corner reflectors inside the hull.

That concludes the portions of the program on target strength. I do wish again to emphasize that the average value of 32.7 db is high, and that it was surprising to us when it was obtained.

DISCUSSION

<u>Captain Pryor</u>: Do you expect to check that at other frequencies later?

<u>Mr. Urick</u>: Yes. Dr. Saxton will mention the proposed work at 7 kc. It will be very interesting to make similar measurements at a number of frequencies.

<u>Captain Pryor</u>: That would tend to lead you to believe that the failure to get good echoes at bow aspect was not due to any difference in target strength as well as the fact that your transducers are probably not pointed exactly in the right direction because the angle subtended is much smaller.

<u>Dr. Saxton</u>: Yes. Of course, this is at 10 kc. Now at 25 kc, the old picture is correct as far as we know.

<u>Captain Pryor</u>: Is there any significance to the double feature of the echoes you showed in Figure 12? The target echoes seem to be split into two main parts. I'm not referring to the delayed echo now, but to the main echoes which seem to have two parts.

<u>Captain McCain</u>: I think there may have been reverberations.

<u>Mr. Urick</u>: The first part was reverberation. This dies off very rapidly; the reverberation background is very low at the time the echoes arrive.

<u>Captain Pryor</u>: How about pointing out the main echo and delayed echo?

<u>Mr. Urick</u>: One thousand yards. This is a very compressed scale.

EQUIPMENT PERFORMANCE REQUIRED
Dr. H. L. Saxton

I would like to add to the picture of losses, the idea of net loss for the round trip which involves, in addition to propagation losses which we previously showed for various cases, the loss at bottom reflection and the gain due to target strength, factors which have now been covered by Mr. Urick. I want to arrive at some figures which I don't expect to mean much at this point, but at a later time we can refer to them to see how equipment parameters add up toward meeting them. In Figure 15, the three cases tabulated in Figure 2 are repeated. In the fifth column a reflection loss of 22 db has been added for all cases. This is obtained by taking the 11 db that Mr. Urick mentioned on both the outward and the return trips. We now have data taken in the Atlantic which has not been returned to the Laboratory yet and we shall within a matter of days have a check on whether this same reflection loss is observed*. We know that good bottom echoes were obtained on this Atlantic trip to Bermuda and working out of Bermuda, but we do not have the actual processing of the data to show what the bottom reflection loss was. The target strength of 32 db has been entered in the sixth column of Figure 15. When we subtract the target strength from the propagation loss and add the reflection loss, we get a net loss of the round trip which is shown in the last column. This net loss means that if we have an intensity I_o at one yard from the source, the intensity of the echo which comes back to our receiving hydrophone is at a level below I_o by the net loss. With an ocean depth of 900 feet and 13.5 kiloyards horizontal range, 184 db is lost and the echo intensity is I_o - 184 db.

Let us look briefly at the over-all picture including equipment and operator. Figure 16 shows the parts of a complete system. There is shown a power P' going into the transmitting transducer and an acoustic power P from the transducer into the water. This gives rise to an intensity at one yard from the source given by the power P plus the directivity index plus 72. And so $I_o = P + \Delta + 72$ is what is sent out. The power, in traveling to the target and back, suffers a net loss (tabulated in Figure 15), so the intensity arriving back is what started out minus this net loss, or $P + \Delta + 72$ - net loss.

At the receiving transducer we have the signal and background noise, the latter at a level of -15 db in a 1-kc band at 10 kc at 12.5 knots ship speed. The transducer has a directivity, Δ , so that the effective

*A loss somewhat less than 11 db was observed.

masking noise level coming out of the transducer in decibels is $-15 - \Delta$.

Nothing has been said so far about reverberations, other than Mr. Urick's remarks that reverberations always die down into noise before the echoes are received. When we had good paths, we obtained echoes, and the limitation that was found only at very-long range was due to noise background since reverberations had completely died out. If we did not have good channels, we sometimes failed to obtain echoes and it is possible that we were reverberation-limited in those cases. In Figure 16, we have indicated that we have noise masking to combat, since our interest is in long ranges with acceptably good ducts.

We have indicated that the noise masking level is $-15 - \Delta$ db. If the echo level in db ($P + 72 + \Delta$ - net round-trip loss) then equals the noise-masking level in db by the recognition differential (δ), detection probability on a single ping with the target on the sound-beam axis is 50%. This is expressed by the equation hown in Figure 16.

$$(P + 72 + \Delta - \text{net round trip loss}) - \left(\frac{15}{2} - \Delta\right) = \delta$$

A more convenient form of the equation involves equipment parameters only on the left and everything else on the right. This is also shown in Figure 16 as

$$P + 2\Delta - \delta = \text{net round-trip loss} - 87$$

If equipment is to be designed so that $P + 2\Delta - \delta$ is as high as feasible, one quantity which may be the cheapest to improve is δ , the recognition differential. This is defined as the ratio (expressed in db) of signal having a 50% probability of detection to interfering noise in a 1000-cycle band centered at signal frequency. While we have shown explicitly power rather than energy in our echo-ranging equations, actually, the amount of energy in the pulse is the important thing, because longer pulses yield higher recognition differentials. We can do about as well against a noise background with double the pulse length and half the power. We therefore have no thoughts of going to 0.01 present pulse lengths (except for classification) since this would not permit increasing the power a hundredfold or even tenfold.

δ for a half-second pulse, with the unaided ear as a detector (of course, we assume gain and frequency translation), is -13 db in the Laboratory and perhaps -10 db in the field, which means that we can detect 50% of the time a signal 10 db below the masking noise in a 1000-cycle band. Efforts to improve on the ear have generally led to complicated systems. The most recent development along this line is relatively simple in construction and I will now call on Mr. Bayston who has supervised the experimental work, to describe this development.

A RECENT APPROACH TO HIGH RECOGNITION

T. E. Bayston, Sonar Systems Branch

As Dr. Saxton has mentioned, an important part of this problem of extending the detection range is the development of reception equipment and techniques which will give the maximum recognition differential. Any improvement that we can obtain in the recognition differential reflects a corresponding improvement in the detection range; and, conversely, anything less than maximum detection efficiency will rob an otherwise good sonar system of much of its effectiveness. We, in the Reception Unit, are primarily concerned with this problem of developing reception techniques and reception equipment which will give us the maximum possible recognition differential. Since we are not the only ones in the Sound Division that are working on this problem, we have confined our own efforts to an area in which I believe there is little work being done elsewhere. We have been concerned primarily with 2-channel receivers or phase-sensitive devices such as right-left indicators, binaural receivers, and sector-scan indicators.

Some of you may be familiar with the sector-scan indicator, or SSI. It was used in the type-A integrated-sonar system which was developed here at the Laboratory and underwent sea trials on the USS FOSS. The SSI is also used as a basic part of the XDG sonar system now undergoing sea trials at Key West on the USS SEA CAT. The operation of the SSI is fairly straightforward and was understood, at least here in the Laboratory, for c-w signals. Exactly how it handles c-w signals was understood but we were not too sure until recently as to how it handles noise. Recently we undertook a study of the SSI to determine how this device handled noise and what it did to the signal-to-noise ratio.

The SSI was originally developed and used as a train-error or bearing-error indicator. It indicates the angle off the axis from which the energy is being received by the transducer. I would like to sketch briefly what happens to a c-w signal in the SSI as a basis for understanding what happens with noise. Figure 17 is a simple block diagram of a typical SSI. Since this is a 2-channel device, it uses a split transducer and the signal frequency at the input of the SSI is indicated as F_o. This is amplified by conventional SF amplifiers. The two signals are then mixed in two mixers by two local oscillators at a slightly different frequency, oscillator 1 being at frequency G_1 and oscillator 2 being at some frequency G_2. The intermediate frequency selected is usually the difference between the oscillator and the incoming signals, to give a signal in the upper IF of $G_1 - F_o$, and a signal in the lower IF amplifier of $G_2 - F_o$. The signals at the output of the IF amplifiers are mixed in a third converter to give an output. The difference frequency is usually selected here as the frequency desired. This difference frequency becomes $G_1 - G_2$. You will notice the frequency here, $G_1 - G_2$, is independent of the incoming frequency F_o.

That means regardless of what the doppler is, the frequency out of the third mixer is always $G_1 - G_2$. In the conventional use of the SSI, this frequency, $G_1 - G_2$, is sent through a video amplifier where it is limited and differentiated to make brightening pips which are applied to the control grid of the cathode-ray tube. The two local oscillators are also mixed (Mixer No. 4) to give a frequency $G_1 - G_2$, and this difference frequency is sent through suitable amplifiers to synchronize a horizontal sweep on the cathode-ray tube. Since the frequency of the horizontal sweep is $G_1 - G_2$ and the frequency at the brightening grid is $G_1 - G_2$, we shall get one brightening pip for each horizontal sweep. It follows from the theory of these mixers that any change in phase between the two input signals will result in a change in phase of the brightening pips (with reference to the sweep) by the same amount. Consequently, we have a phase-indicating device which operates as a train- or bearing-error indicator.

To this point, handling of the signal plus the noise in the signal channels is fairly straightforward. But we were not too sure about what happens at the output of this third mixer -- just exactly what happens to the signal and noise ratio. I've indicated a narrow band filter at this point in the circuit. The use of that filter is what we've been studying just recently.

When these sector-scan indicators are operated in the field with the gain turned up to a point to where they brighten on background noise, or ambient-water noise, the brightening appears to be positioned quite randomly. In order to simulate in the laboratory so that we could evaluate these devices, we had two possible approaches. We could use a simulated noise in which we devised some scheme to shift the phase of the noise randomly in one of the channels to give us a random brightening or we could use two independent noise generators. The second method was the one that we adopted, that of using two independent noise generators to supply noise to each of these channels to simulate ambient-water noise or background noise. This method results in a display on the SSI that very closely duplicated that obtained under actual operating conditions at sea. This leads to a lot of thought about the type of noise in the water at the two halves of the transducer. We have more or less come to the conclusion that the noise is to a great extent incoherent, or uncorrelated, between the two halves of the transducer for the frequencies that we usually use in the sizes of the transducers normally employed. As previously mentioned, we undertook a study of what happens to the signal and the noise at the output of Mixer No. 3.

We attempted to analyze the output of that filter with a spectrum-analyzer to ascertain what sort of distribution we had in frequency and noise. The results were not very satisfactory. So as a first step we used two independent noise bands, one centered at 9 kc and one centered at 14 kc, mixed them together in a simple mixer, and analyzed its output with a spectrum analyzer to find the frequency distribution. Figure 18 shows the results of the spectrum analysis. It shows the difference frequency band at 5 kc, the two original bands of frequencies, and a fourth band of intrachannel noise -- a low frequency band due to the noise in each channel beating with itself to produce low-frequency components. The reason we did not have much success in analyzing an earlier SSI was that the difference frequency was low compared to the signal-channel bandwidth; consequently, the difference-frequency band was masked by the low-frequency noise. This difference-frequency band of noise as it comes out of the mixer is approximately twice as wide as the original bands of noise at the original frequency.

The result of inserting a c-w signal with the two original bands of noise is shown in Figure 19. The spikes shown represent the c-w signal that was centered at 9 kc and at 14 kc to give us a difference frequency signal of 5 kc. It is interesting to note that as we analyzed all bands with the 2-cycle band analyzer filter we got signal-to-noise ratios in the same order of magnitudes at the difference frequencies as in the two original bands.

With this in mind, we took an existing SSI and modified it to raise the difference frequency out of the intrachannel noise. The original equipment had a difference frequency (difference in IF channel frequencies) of some 400 cycles. The difference frequency was fairly well masked by the intrachannel noise. A difference frequency of 4 kc brought the signal out of that noise and gave a reasonable distribution. Figure 20 shows the distribution of the noise resulting from incoherent noise fed into the input of the SSI. It shows that this noise is distributed symetrically about the difference frequency.

At this point we inquired as to what happened to a coherent noise, or a target noise, introduced into the SSI. The SSI works very well on screw noises, which indicates that these noises must be coherent. So we introduced a coherent noise into the input of this modified SSI along with the incoherent background noise and again scanned the output of the third mixer with a spectrum analyzer. Figure 21 shows the coherent noise above the incoherent noise. Note that the noise-to-noise ratio at the input of the SSI was unity, or zero db -- that is, the coherent noise and the incoherent noise were both of the same value. At the output of this 2-cycle filter we got an increase in the noise-to-noise ratio in the order of 18 db which shows the tremendous improvement that can be obtained by this SSI because it concentrates, or stacks nearly all the energy from the coherent noise into a single-frequency band at the difference frequency. The incoherent noise is still spread about in a band that is twice as wide as the original IF band so that a narrow filter placed after the second detector can reject most of it and give us a decided improvement in the noise-to-noise ratio.

Figure 21 shows the results of broadening the bandwidth in order to confirm some points on a curve so that we could develop a theory or develop the mathematics for this phenomenon. We opened the sound-channel bandwidth of this modified SSI (originally 500 cycles) out to 2 kc. You notice with the wider bandwidth, the difference frequency now begins to fall and be masked by the intrachannel noise from each channel. But at this point, we get an improvement in the order of 20-22 db in a 2-cycle band. Now Figure 23 shows the results of opening up the bandwidth to 4 kc with a 4-kc difference frequency. We are now getting into trouble with the noise from each channel masking the difference-frequency noise. Nevertheless, we get an improvement that is in the order of 25 db or so.

We built a filter to go in the output of Mixer No. 3, a narrow filter which had variable bandwidth, and examined the output for noise-to-noise ratios to determine the improvement that could be obtained. The lower curve of Figure 24 shows an IF bandwidth of 50 cycles, and a narrow filter bandwidth of from ½ to 10 cycles. This curve shows that with a noise-to-noise ratio of unity in the input of the SSI, we get an improvement that ranges from 6 db up to something like 17 db, depending on narrow-filter bandwidth. With a 500 cycle IF band, we get something in the order of 8 db better than for the 50-cycle IF band. With the half-cycle filter at the output, we get an improvement in the order of 24 db in the noise-to-noise ratio. With a 5000-cycle IF band, a substantial additional improvement is to be expected. It is possible with a device of this type to open the bandwidth of the front end wide enough to accept all the major (or important) noise that is emitted by an enemy submarine or target vessel and then process it through a very narrow band filter to get an improvement in the noise-to-noise ratio.

We now leave consideration of noise signals and consider c-w signals. For a moment, refer back to Figure 17. In our work with signal-to-noise ratios, of course, the obvious advantage is in the narrow filter at the output of Mixer No. 3. Since the returning echo always has the doppler information removed by the SSI, regardless of what the doppler is, the signal is always at the frequency $G_1 - G_2$ at the output of Mixer No. 3. Therefore, we can put in at this point a filter with a bandwidth that is optimum for the pulse length we are using. For example, for a ½-second pulse, a bandwidth of this filter would be in the order of 2 cycles. The IF bandwidth had to be something in the order of 200 cycles at, say 10 kc, in order to accommodate the doppler. So this gives us the advantage of accommodating the doppler and at the same time using a narrow filter with which to process the signal and noise. In one instance, in a rather rough check which we made, we used a signal-channel bandwidth ahead of Mixer No. 3 of 50 cycles and a narrow filter of 1 cycle and obtained 50% recognition on a signal-to-noise ratio of -5 db as measured in the 50-cycle band. That, referred to a 1000-cycle band, as is customary, would be equivalent to -18 db. A recognition differential of -18 db is appreciably better than what can be obtained with the unaided ear, and it at least shows that we are on the right track.

There is an additional method by which to process the information which I have indicated in the lower part of Figure 17. We take the output of the third mixer, in which the two IF outputs are mixed, and pass it through the narrow filter into a balanced mixer in which it is mixed with the reference frequency obtained from Mixer No. 4 to get a zero-beat phenomena in which the balanced mixer takes out any output due to the reference frequency and leaves us only an output due to the difference-frequency components. The noise components which lie on either side of $G_1 - G_2$, and those noise components that lie at $G_1 - G_2$ will cause a distribution at the output of the balanced mixer from dc out to some frequency determined by the narrow filter. A low-pass filter then can be placed at the output of the balanced mixer to exclude the noise components that lie on all frequencies except $G_1 - G_2$ to give us the resulting improvement in our recognition.

Dr. Saxton has developed a mathematical treatment for this device in which he shows that, if the mixers are square-law devices, the products we get out are the same as that of the correlation function. This low-pass filter, of course, acts like an integration device and averaging device as is necessary in the correlation function. I do not have any data on the balanced mixer in a form that I can present at this time, but we have made a few experiments with this type of circuit and we get an output that resembles very closely the output that we would expect from a true correlation device. As I mentioned, the only concrete data that I have so far in the laboratory is the recognition differential result of -18 db. These results have been partially confirmed in the field by an SSI on the USS GUAVINA and an SSI on the USS SEA CAT, I say "partially confirmed" because the only field data we have on this device is qualitative. I have a report from the SEA CAT that the modification to the SSI to give this type of circuit resulted in "a manyfold increase in sensitivity," but exactly what that means in range or db, we have not determined.

DISCUSSION

Dr. Saxton: I have, perhaps a little later word on results obtained by the SEA CAT. We were able to track a target to 11,000 yards on 24 kc with this device which range is better than double what was usually obtained with the previous equipment.

Captain Pryor: Were you using propellers?

Dr. Saxton: Using propellers, listening.

Captain Pryor: Were you using the frequency spectrum of the propellers as your signal?

Dr. Saxton: Yes, at 24 kc. That seems to me to be the longest range I've ever heard of at that particular frequency which is not a good frequency for obtaining long range.

Mr. Bayston has presented the material that we thought appropriate for this meeting and we feel highly encouraged by the results of this device. We know quite a bit more about it than what has been given; we know enough now to write a fairly comprehensive report and one will be forthcoming.

A review of background data which includes reports on the two highlights has so far been presented. Now let us ask the question, is it feasible to build 10-kc equipment for the fleet which will give the long ranges via the bottom? Can we at the same time exploit surface bounded ducts when they exist? For a discussion of these questions, I now call on Mr. Wilson, the Head of our Sonar Systems Branch.

PRACTICALITY OF 10-KC SONAR SYSTEM

M. S. Wilson, Sonar Systems Branch

A practical sonar system for long-range search is possible using presently known techniques. We have had some six months experience operationally, with the experimental 10-kc sonar system installed on the USS GUAVINA in the Key West area. The performance of this sonar has been reported and you no doubt are well acquainted with the fact that relatively long-range contacts are consistently observed. The purpose of this discussion is to outline a practical system based on our experience with the GUAVINA installation and to project our ideas toward a surface ship installation.

I intend to outline for you the simplest sonar system required for obtaining relatively long ranges, say 15 kiloyards. I wish to stress that there are many ideas which I shall not include, even though they might add somewhat to performance, in order to keep this system simple.

Figure 25 shows a block diagram of a complete but simplified system. The electronic portion can be built into three main stacks composed of: 1) the Operator's console, which can be remote from the rest of the equipment, 2) a rack for the receiver and SSI, and 3) a rack for the high-power driver. Other necessary equipment not requiring rack-type mounting includes the rectifier and blower, the energy storage and the control equipment, and the train and tilt gear. The transducer and transducer housing will be discussed a little later.

The electronics is relatively simple and imposes no great problem of training and maintenance. A receiver is shown which can be as simple as a straightforward audio channel, or the more complex configuration of a multichannel design. The SSI is shown since it can obtain a high recognition differential with very simple circuitry. The transfer relay unit is a simple relay and is shown separately only to illustrate its function. A program search control is a simple mechanical means of assuring even search coverage with minimum attention and fatigue of the operator. The driver is capable of high power and long pulse length. There are no problems associated with the electronics since the present state of the art is adequate for immediate production. The interest in this portion of the system lies in the energy-storage function. We have been successful in using either electrical storage in capacitors or mechanical storage by means of a flywheel on the generator. Probably the latter would be superior for Fleet use because of weight and space factors and especially from personnel hazard considerations.

The greatest problem associated with a system for surface craft installation is the mounting of the transducer in the dome, although the future solution of this problem will no doubt consist of hull-mounted hydrophones, arrays for listening, and a nondirectional transmitting transducer. The immediate solution probably requires a single transducer for both functions and its associated train-tilt-hoist mechanism in a dome. See Figure 26.

If it proves feasible to tow a fish capable of housing a 3-foot transducer, it may offer an attractive alternative. In this discussion however, we are restricting ourselves to proven components.

I have described in brief a workable system. Now let us see what such a system is capable of in terms of operational performance one could expect. Dr. Saxton and others have reported results of studies, both theoretical and at sea, with experimental equipment aboard the USS GUAVINA, from which studies, performance of the proposed system can closely be anticipated. In surface-bounded channels, one would expect at least 20-kiloyards range with the target in the duct. Targets below the channel present a more difficult problem and the echo ranging path via the bottom appears the only acoustic path getting sufficient energy to the target and back. We now have experimental evidence of the loss encountered by this path and if we put figures in our equation for this path we can closely predict performance.

What is required has been shown by Dr. Saxton. You will recall that for 15-kiloyards horizontal range 106 db total must be obtained using a frequency of 10 kc. The equipment parameters of this proposed system are the power ($48\frac{1}{2}$ db), twice the directivity index (50 db), and a recognition differential of -13 -- adding to 111 db total. This total therefore means that the equipment should be fully capable of detecting a target below the channel out to a range of at least 15 kiloyards with some 5 db to spare. With a -20 db recognition differential, using equipment described by Mr. Bayston, this will give some 12 db to spare. However, it would not reach out to 23 kiloyards in deep water at 10 kc. As Dr. Saxton implied, by lowering the frequency, we might lose a bit on the equipment parameters (a few db), but we would be able to reduce the figure which equipment parameters have, to total for 23,000 yards range from 130 db to 105 db which could be obtained with the simple proposed system.

In conclusion, a sonar system can be built at the present time which will detect targets well beyond present fleet detection capabilities. A simple system is proposed which although it does not include all the latest ideas, will nevertheless extend ranges to at least 15 kiloyards, a significant percentage of the time. Thank you.

DISCUSSION

Captain Pryor: Would you tell us what ship speed this is calculated for?

Mr. Wilson: These figures assume the self noise of a $12\frac{1}{2}$-knot surface ship, a destroyer.

OPERATIONAL PROBLEMS AND FUTURE RESEARCH

Dr. H. L. Saxton, Superintendent, Sound Division

Now that it has been shown that a 10-kc equipment is feasible and should give an increase in range of about an order of magnitude a high percentage of the time, we believe that the Navy will want a low-frequency-search equipment on its ships. There are, however, a number of questions that need to be answered. First is the question of area coverage, since range alone is not enough. Let us suppose that we are operating in 2,000 fathoms of water with a vertical beam width of 18° between the 10-db down points. We wish to rely on only the central portion of this beam with rays between 20° and 30° downward tilt. This gives coverage at horizontal ranges of 14 to 22 kiloyards. However, suppose we choose to focus our attention on 15 to 20 kiloyards range. If we wait for the first ping to return from 20 kiloyards before pinging again, we must wait 25 seconds. Suppose that, instead, we ping three times before listening for the first return. We will have to use three different frequencies such as 9.5, 10 and 10.5 kc in order that the reverberations from the third ping will not interfere with reception of the first echo. About 8 seconds elapse between pings, and we can afford to train continuously 4° per ping and still obtain three returns from a single target within the rotating beam. The beam is envisioned as continuously rotating, then, at ½° per second. The receiving beam must be delayed spatially by about 10° relative to the transmitting beam in order to be directed correctly to receive echoes from the extension in range for which we are aiming. If we train from relative bearing 060 to 000, then slew to 300, and then train toward the bow to 000 and so on, we cover the successive areas shown in Figure 27.

With own ship assumed at 12½ knots, the extension in range is 15 kiloyards to 20 kiloyards, or from a_1 to b_1 at relative bearing 060 in the figure. We sweep the shaded area around to the bow, then slew over to a_2, b_2 at relative bearing 300, sweep to the bow again, then slew over to a_3, b_3 at 060 and sweep back to the bow again. This is conventional procedure except that in the interests of getting higher speed and because we can get out almost as far toward the sides, we have swept only 60° each side of the bow instead of the usual 90°. Now you will observe that when this is done, by the time that we get back to covering the same area again, the second time starting at a_3, b_3, the advance has been such that we have about 4/5 overlap. It would be impossible for any target to get through without being exposed at least once. If it were moving at 20 knots and timed precisely, it might be able to be at a point just beyond maximum range on one sweep and two sweeps later at a point just less than minimum range. But we always get at least one chance at it. Moreover, if the enemy is making any such speed as 20 knots, we ought to be able to pick him up by listening, and the system should be employed for simultaneous lower-frequency listening.

The area coverage without gaps is 46.5 square miles per sweep in a little over 4 minutes. That's a sweep on each side -- a complete coverage on both sides from 60° to the bow, assuming that with the five coverages of the same area because of overlap, we have a 75% probability of detecting anything in that area on at least one of the several sweeps through. Multiplying this .75 times the swathwidth times own speed, we obtain an area-coverage rate of 160 square miles per hour. Assuming that QHB at the same speed has a 100% probability of detection out to 2000 yards, and a 50% probability of detection from 2000 to 3000 yards, its coverage rate is computed to be 31 square miles per hour. There is a difference of about 5 to 1 in coverage rate. We have here the possibility of a fivefold increase in coverage rate and at the same time coverage of that area where detection will be in time for us to act. We give these results not with any idea of having specified an ultimate operational procedure, but rather to enable estimating roughly the possible effectiveness of some feasible procedure. We conclude that this method looks effective. For official quantitative calculations and determination of optimum sweep procedure, we prefer to depend on OEG.

Another operational problem arises from the desirability of covering the surface-bounded duct when it exists. We feel that this should be done, and we envision shaping the transducer beam to permit radiation to the duct and to the bottom simultaneously and to permit reception from both simultaneously. We suggest that a secondary lobe down 10 db might be adequate for the duct, and this would not appreciably decrease the energy radiated on the tilted main lobe or the directivity index for reception via the bottom. Another solution might be to direct one ping in two or three into the duct.

Another operational problem is that of ship development to utilize best the new mode of operation. This I do not intend to go into, but the existence of such problems should be pointed out.

Operator training is going to be difficult unless the controlled targets go deep, because operators will otherwise prefer using the surface duct and may get into bad habits. That is to say, if our controlled targets always remain in the surface ducts, the operator will have no occasion to tilt down 30° or 25°. Furthermore, training in the use of bottom reflection is impossible in the Key West operating area because the bottom there does not reflect. Incidentally, there's one good point about having a place where there's no bottom reflection. Sometimes you like to know what you get via the direct path only, and you can be confident that whatever you get in Key West is via the direct path.

Now I would like to discuss some future research. We are left with many research problems. First we must actually work in deep water with a submarine target and obtain real echoes before the Navy should be willing to go into production on anything. So far no submarine target has been available to us in deep water, nor have we until now come to the point where we were ready to request such availability. We have now requested a 3-week Guantanamo trip in November with a guppy submarine and additionally a number of overnight trips from Key West to deep water with a fleet-type submarine. We anticipated, when I wrote this, adding convincing proof to our claims which can now be based only on calculations. We have a lot of pieces which we have presented here which add up to certain results. But it would be much better to get real echoes and bring back recordings for you to see or hear, where we had echo ranges via the bottom out to ranges, of say, 20,000 yards. The latest information is that we probably won't get our cruise to Guantanamo which we requested, because of a week which is to be used in type training. This will cut down our total time to $4\frac{1}{2}$ weeks and there is no plan at the present time on the part of the Navy to provide any trip to Guantanamo. However, to compensate for this, we have feared that the GUAVINA would have to go into an overhaul period in December, and it now appears after recent inspection in which she was found to be in unusually good condition, that this might be delayed until something like March or February at least. This would allow us one more operating period before the GUAVINA goes into overhaul. Possibly out of the next two operating periods we shall be able to get what we most immediately need.

There is a question of whether the target strength of the USS CHOPPER at 10 kc is characteristic. Even if characteristic, it should be confirmed. Exercises with the guppy-type and other fleet submarines should settle this question. There is the question of mechanism of reflection whereby such high target strength is evidenced. Can it be corner reflectors as suggested by Dr. Fay of MIT? If so, will an enemy have eliminated this type of reflection? Should our submarines start eliminating it?

Some concern has been expressed relative to target classification at long range with the thought that spurious echoes might be confusing. If the high target strength is dependable, echo strength may be a sufficient criterion for classification. We certainly have no reason to believe that there will be any other targets out there of 30-db strength. Furthermore, there is some evidence that 10 kc is not reflected from wakes. This may be helpful. However, research along this line, must in our opinion, be accelerated. We have the range-rate indicator, which is a sensitive device for indicating echo quality and especially for delineating details of frequency shifts. We have the SSI, which can under favorable conditions show aspect. We have both horizontal and vertical SSI with which to experiment. Then there is the question of analyzing amplitude modulation. I have here some echoes which we have recorded. Mr. Baker will play some of these echoes while you watch them on an A-scan.

Mr. H. R. Baker: (Recordings were reproduced of beam-aspect echoes from the USS SEA CAT at 11,000 yards range -- keying range 15 kiloyards. Stern and quarter aspect echoes were also presented from the target opening range on a zigzag course.)

There is nothing about the modulation of the echoes (Fig. 28) that appears striking. There is some variation from ping to ping, but as you listen to echoes they sound steady in tone.

In Figures 29 and 30, we go to stern, changing to quarter aspect with the target running away from us at the short range of approximately 5,000 yards. Note that the echoes are highly amplitude-modulated. You'll notice that there appears to be, in many cases, just about 100% modulation. You can also hear a wavery sound in the audio presentation of the echo which gives these variations. If we can find out what causes the amplitude modulation and can rely upon its occurrence, this may provide a means of classification of some targets with certain aspects.

Dr. Saxton: As far as detection is concerned, perhaps the most important questions are: "How much further should we go down in frequency?"; "What is to be gained?" and "What is the price?" There's no question that downward in frequency is the right direction for utilization of bottom reflections. How far below 10 kc we should go on our first prototype equipment is a matter of speculation. I personally think that a moderate gamble would be profitable, say down to 7 kc. As soon as operating time permits, we propose to take data at 7 kc with the 10-kc equipment, which we found will put out rather high intensity at 7 kc (within a few db of what it will put out at 10 kc.) We propose to take data at 7 kc with existing equipment in order to find out whether target strength holds up, whether the reflection loss is affected (maybe we'll get rid of this 11-db loss observed at 10 kc), and whether the wider beamwidth obtainable with the same equipment can be tolerated. The wider beamwidth in general means higher reverberation levels. To go much further down in frequency than 7 kc would almost surely cost in size of equipment. Five kc is the optimum frequency for 25 kiloyards, as far as noise limitation is concerned, but not greatly superior to 10. There is no reason to go any lower in frequency for such a range. For a range of 50 miles, 2.5 kc is optimum but to get 50 miles takes more than lowering the frequency. Let us go into this a little more deeply.

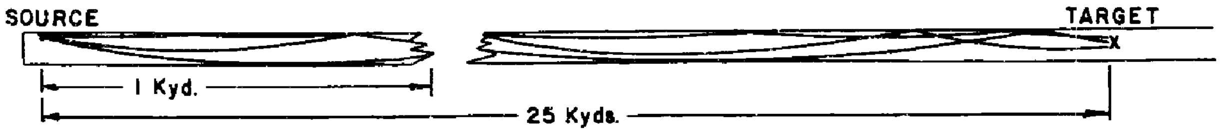
Suppose that we have an equipment of 5 kc, which will give just 25 kiloyards. Now we change over to 2.5 kc holding transducer size and power constant. This latter equipment loses 18 db from higher background noise and wider beamwidths combined and it cannot make this up in 25 kiloyards, and cannot get echoes from 25 kiloyards let alone 50 miles. (It might give echoes over the skip distance, but only in a narrow annular ring.)

Suppose we could double the transducer diameter every time we halve the frequency, and at the same time quadruple the power. At 5 kc (40 kiloyards via the bottom), operation over 1 skip distance should be obtained. At 2.5 kc we should get coverage all the way out to the first skip distance and over 4 skip distances or 140 miles. At such ranges, still lower frequency than 2.5 kc would offer possible advantage. Now a 12-foot diameter transducer at 2.5 kc does not seem particularly feasible. However, a decrease in size to 6 feet for transmission would be acceptable if we could make up the loss by a huge hull-mounted array for reception. Research on both transmitting and receiving arrays is called for. I have indicated that we shall try 7 kc when our operating time is available. It looks as though this will be early next year. Our 5-kc equipment is contingent upon the completion of a 5-kc transducer. We have depended to a considerable extent on the General Electric Company to supply a 5-kc transducer. A preliminary model was far from encouraging since rupture occurred at very low power. We have several other approaches such as our cavity resonators and I personally believe that we can be ready to install by the end of the next calendar year. We propose that this equipment, involving a transducer having an active face of 5-feet diameter, would be installed in a destroyer. Looking still further ahead, we envisage a 2.5-kc equipment using an array for reception, at least, and possibly for transmission as well. We believe that the ranges obtainable would warrant operation with own ship at rest and the lowering of an array to perhaps 50-feet depth. A submarine seems to lend itself best to experimental work. A large semicylindrical transmitting transducer, and an array giving multiple-fixed beams over a total beamwidth of about 60° should establish the results obtainable by such an approach.

CLOSING REMARKS

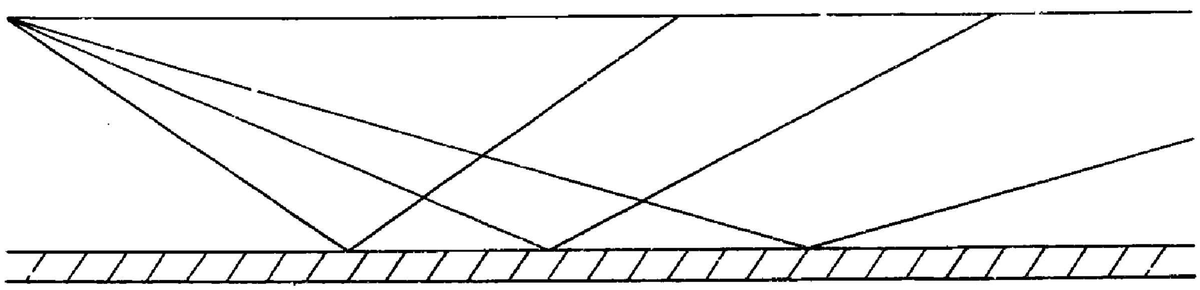
Rear Admiral C. M. Bolster,
Chief of Office of Naval Research

I want to express my appreciation to the Laboratory, to Captain Furth, and to Dr. Saxton for this presentation. I think the Laboratory should be congratulated on a very fine piece of work and I like the approach, I like the matter of fact and down-to-earth way you're going at it. I also want to say that I appreciate having the people from the Bureaus and Offices all down here together to hear the presentation first hand. Getting the word around in this way permits person-to-person contacts and discussions, which are essential for progress. If you who are outside of ONR and NRL will tell us what you don't like, we'll try to do better. Thank you.



PROPAGATION IN SURFACE-BOUNDED DUCT

TWO-WAY LOSS = $20 \log 1000 + 20 \log r + 2(\alpha_o + \alpha_L)R$



PROPAGATION OVER PATH VIA THE BOTTOM

TWO-WAY LOSS = $40 \log r + .02 f^2 R$

Figure 1

COMPUTATION OF LOSS $40 \log r + .02f^2R$ OVER PATH VIA BOTTOM AT 10 KC AND 7 KC

DEPTH	TILT	HORIZONTAL RANGE	PROPAGATION LOSS (10KC)	PROPAGATION LOSS (7KC)
900 f.	15°	13.5 Kyds.	194	180
1800 f.	25°	15.5 Kyds.	203	186
2700 f.	25°	23.2 Kyds.	227	202

Figure 2

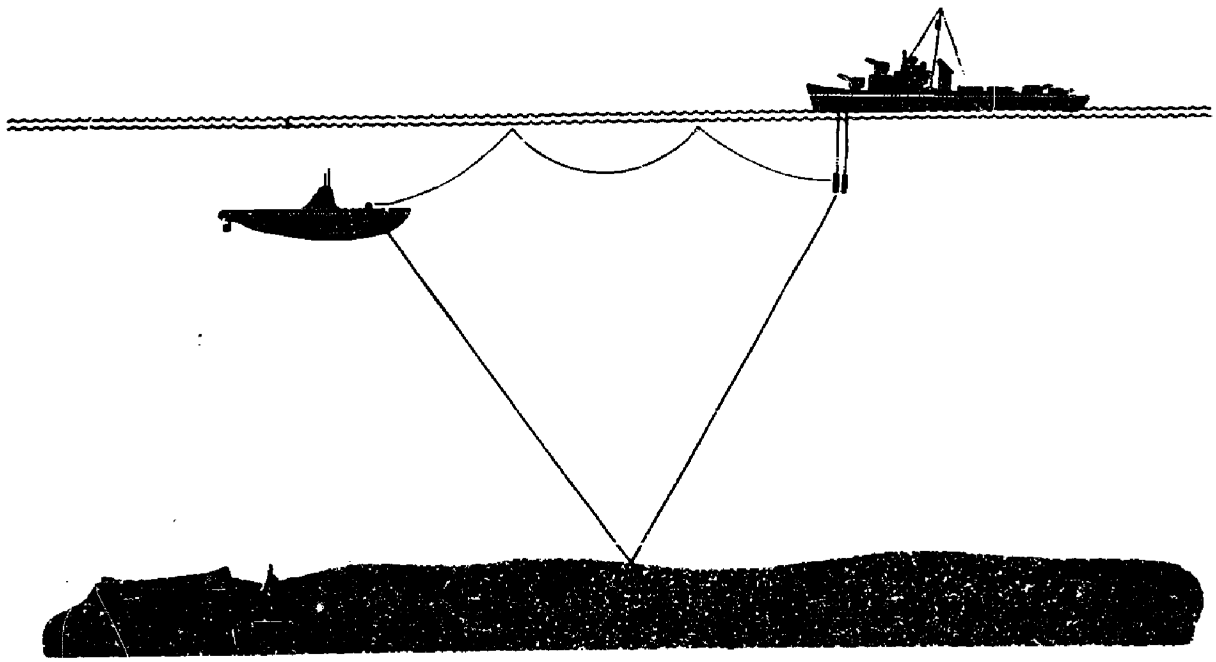


Figure 3

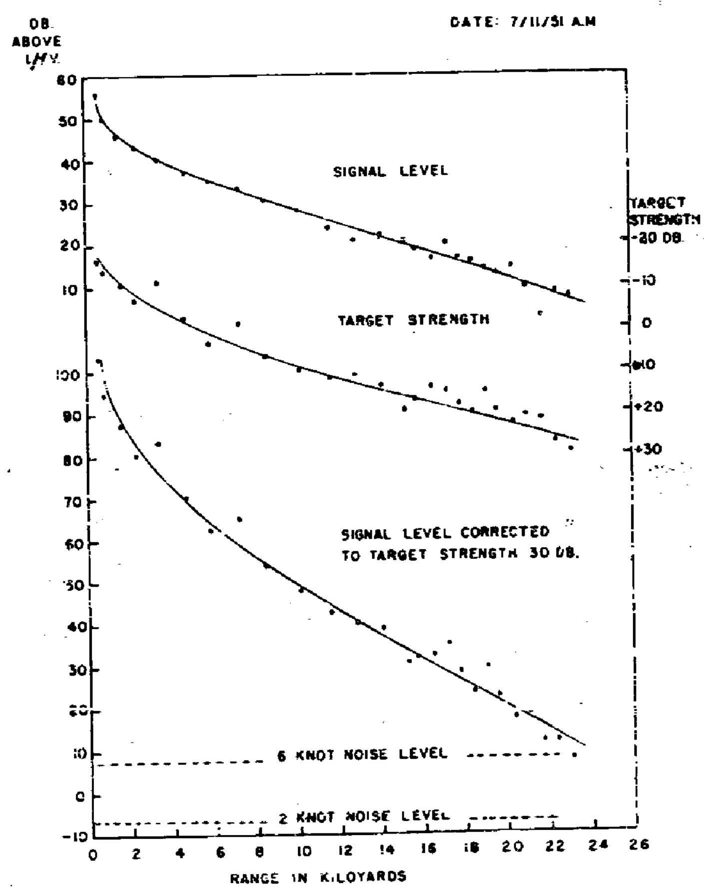


Figure 4

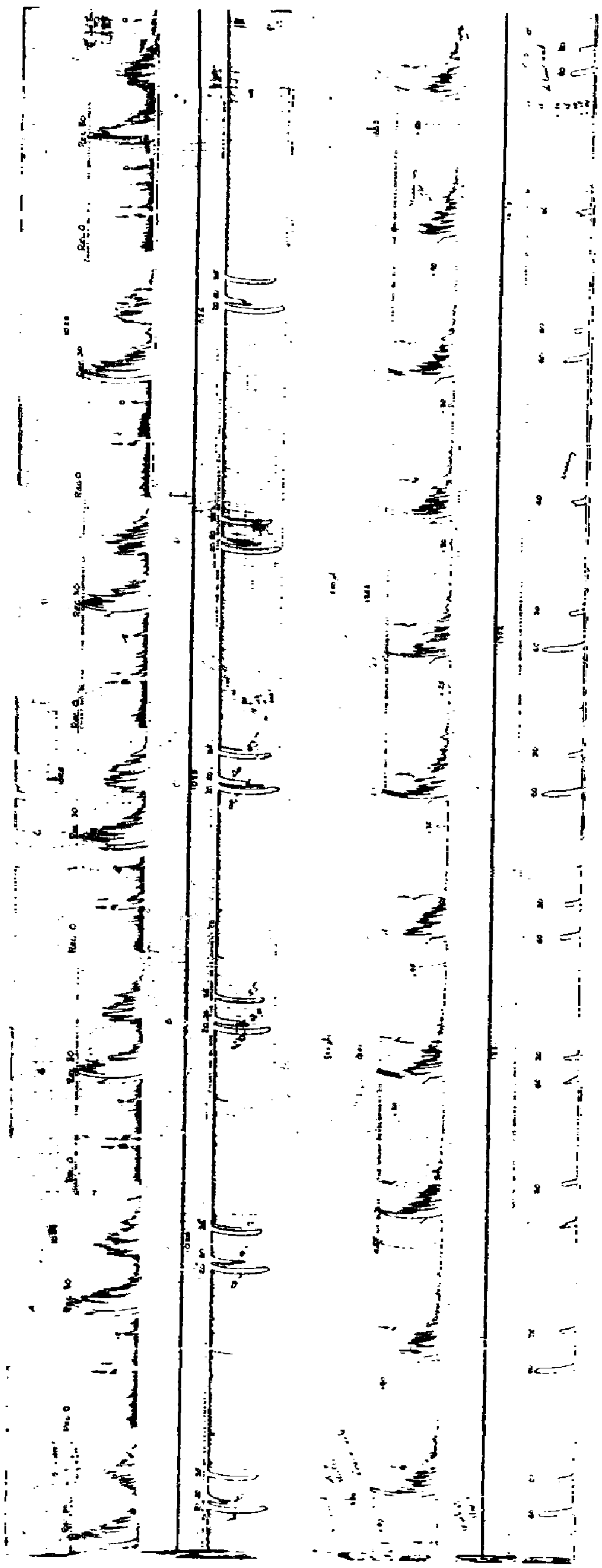


Figure 5

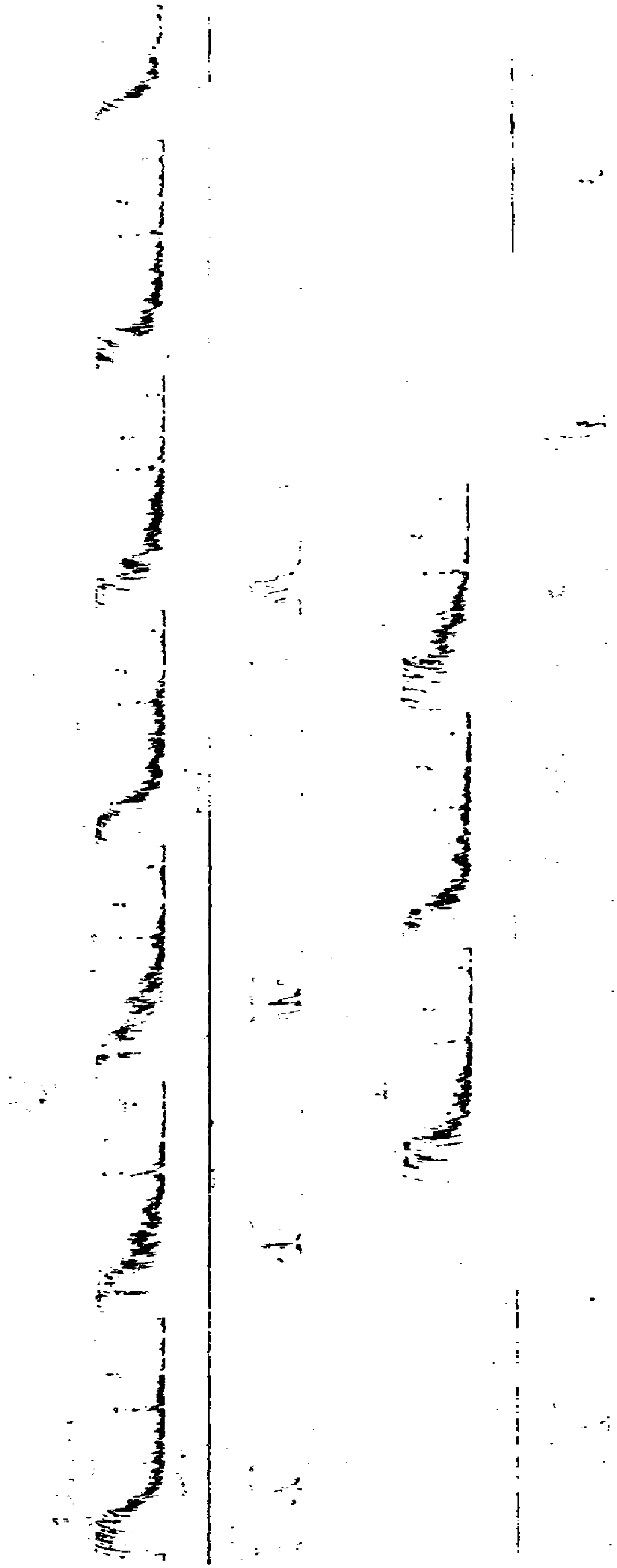


Figure 6

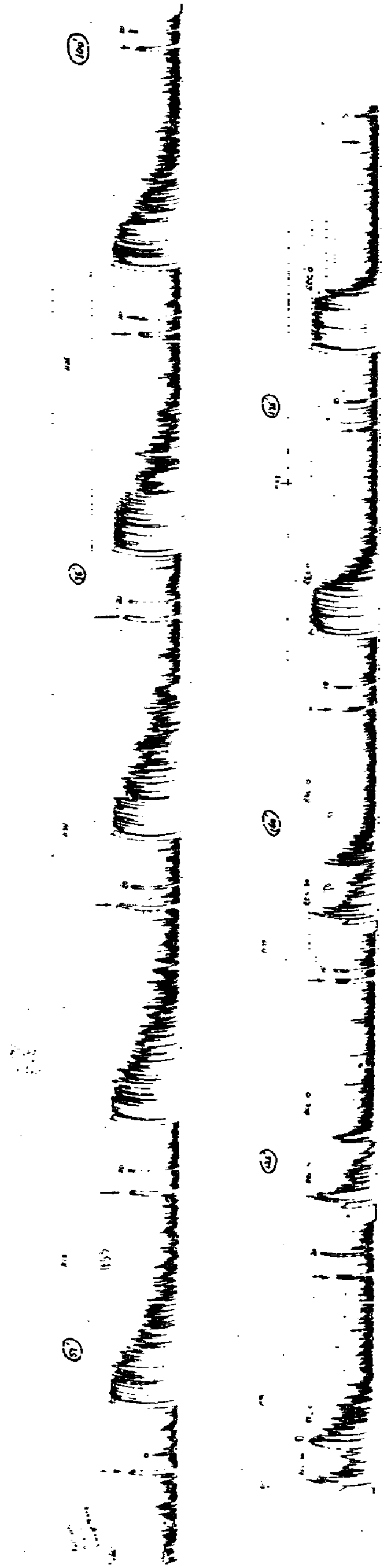


Figure 7

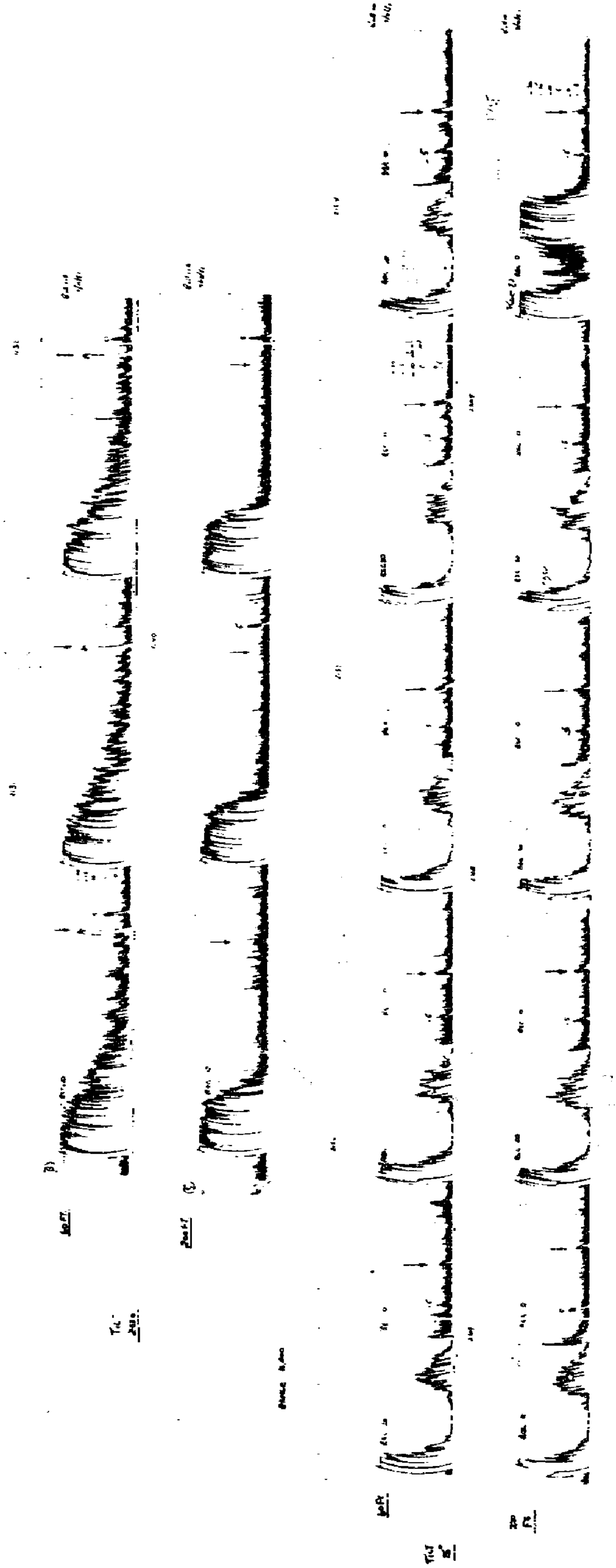


Figure 8

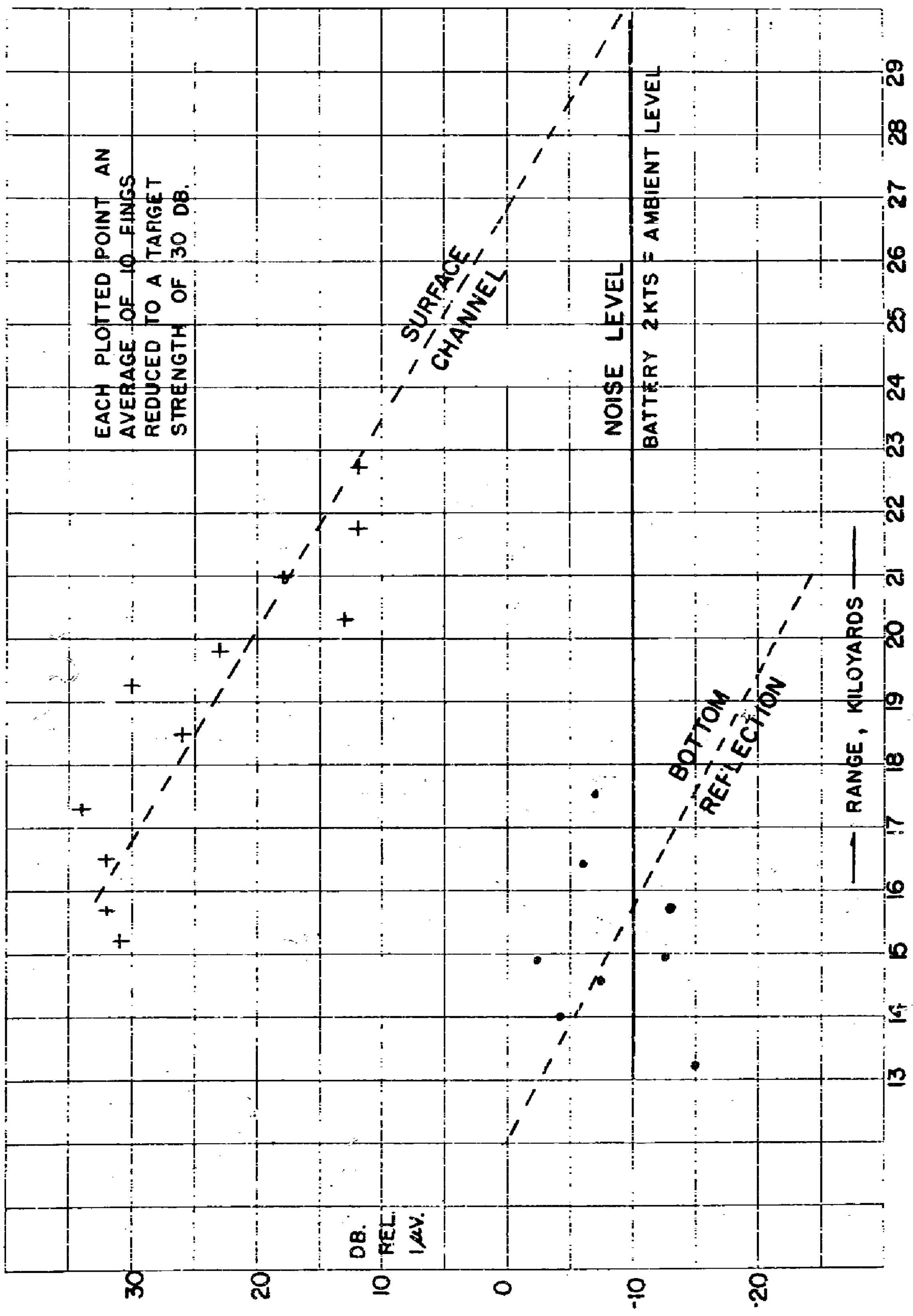
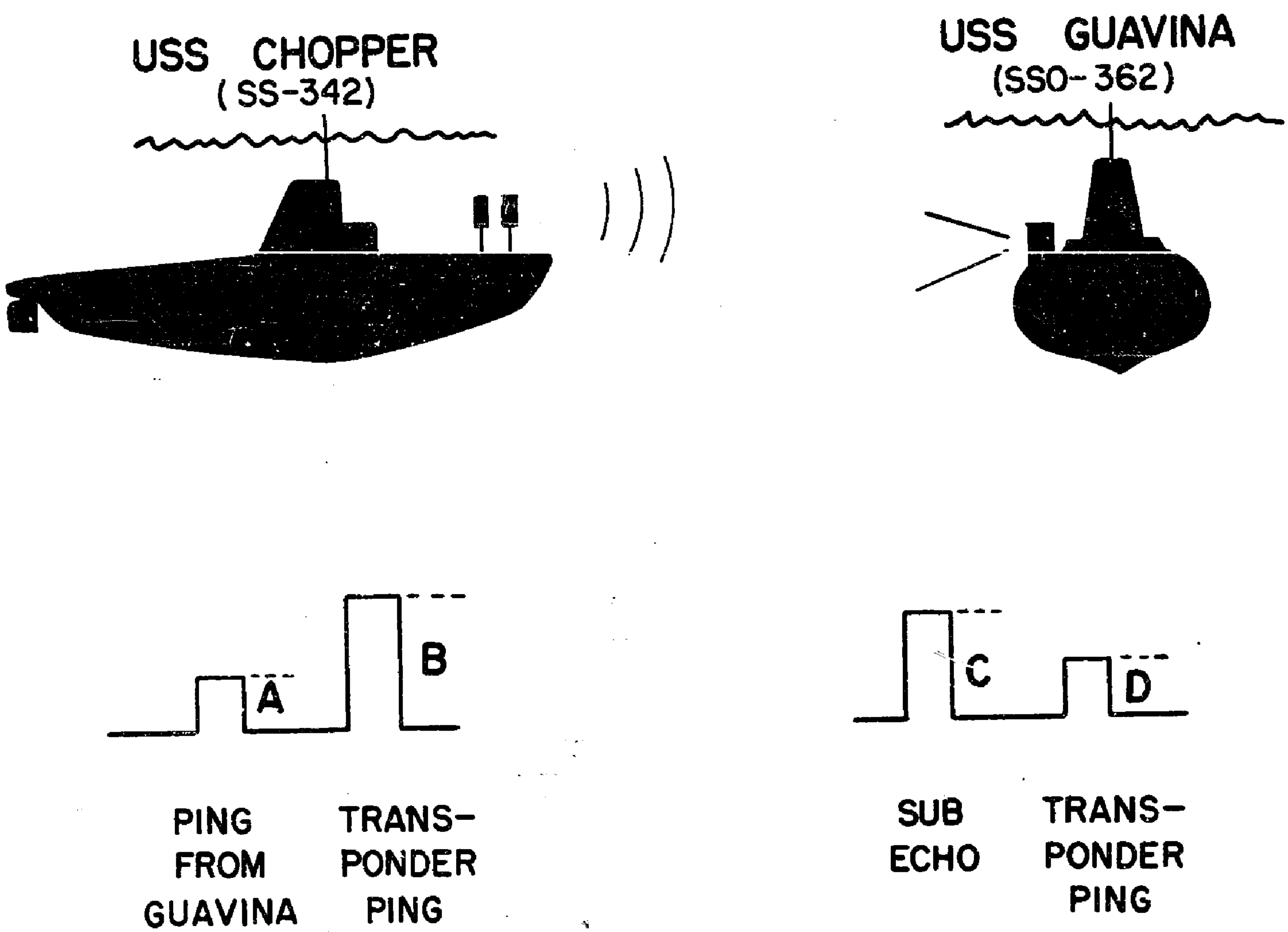

EACH PLOTTED POINT AN AVERAGE OF 10 PINGS REDUCED TO A TARGET STRENGTH OF 30 DB.
SURFACE CHANNEL
NOISE LEVEL
BATTERY 2KTS = AMBIENT LEVEL
BOTTOM REFLECTION
RANGE, KILOYARDS
DB. REL. 1 μV.
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
30 20 10 0 -10 -20

Figure 9



$$T - T' = C - D$$

$$T' = B - A$$

$$\therefore T = (C - D) + (B - A)$$

Figure 10

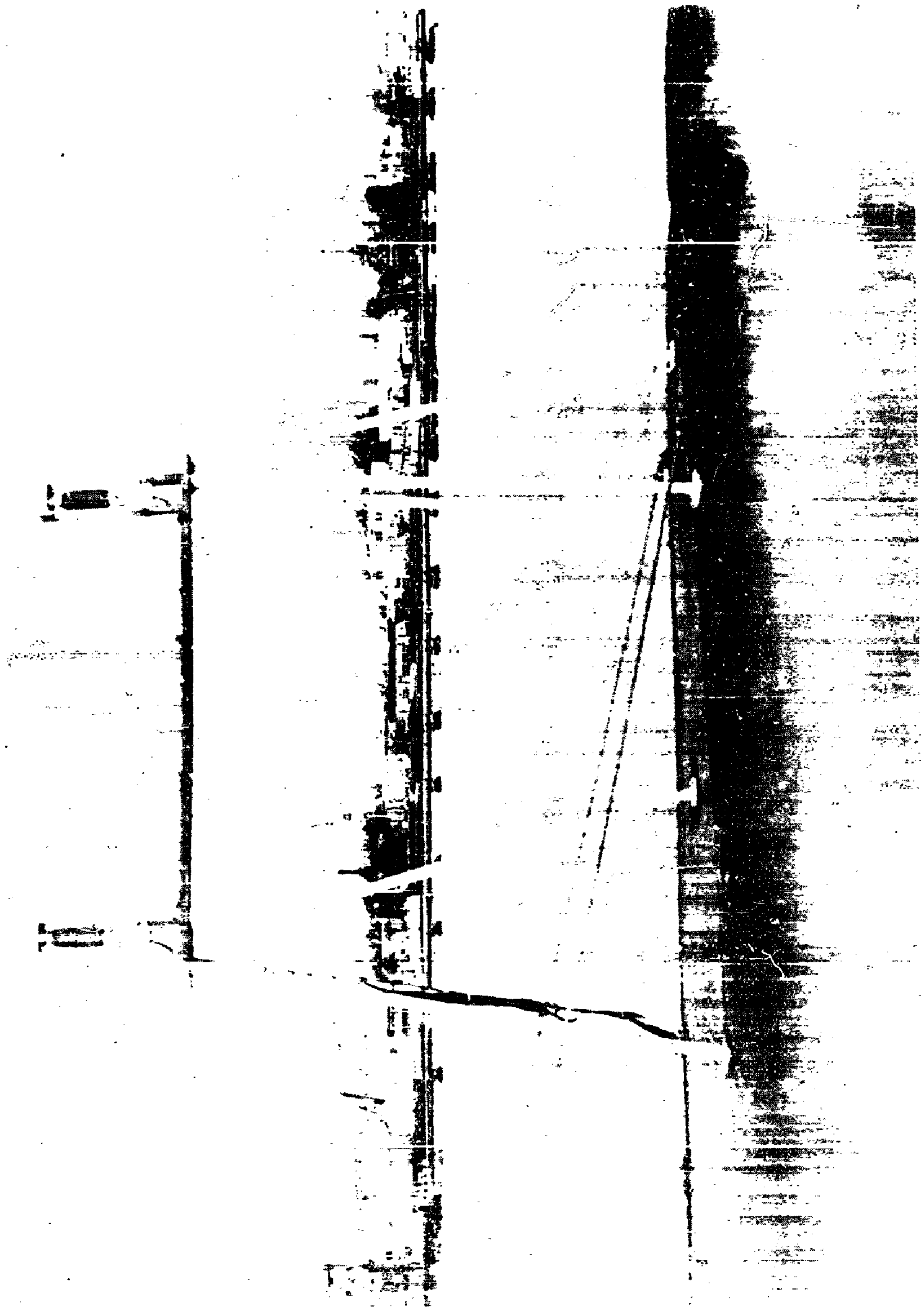


Figure 11

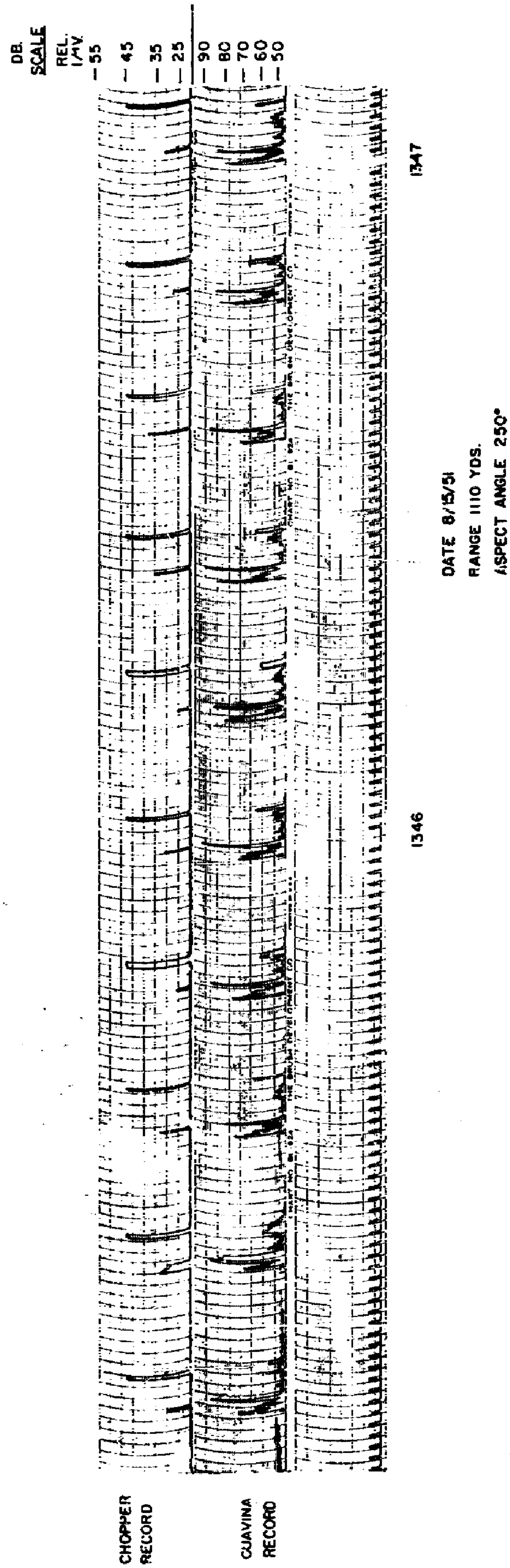

DB. SCALE
REL. 1 MV.
— 55
— 45
— 35
— 25
— 90
— 80
— 70
— 60
— 50
1347
1346
DATE 8/15/51
RANGE 1110 YDS.
ASPECT ANGLE 250°
CHOPPER RECORD
GUAVINA RECORD

Figure 12

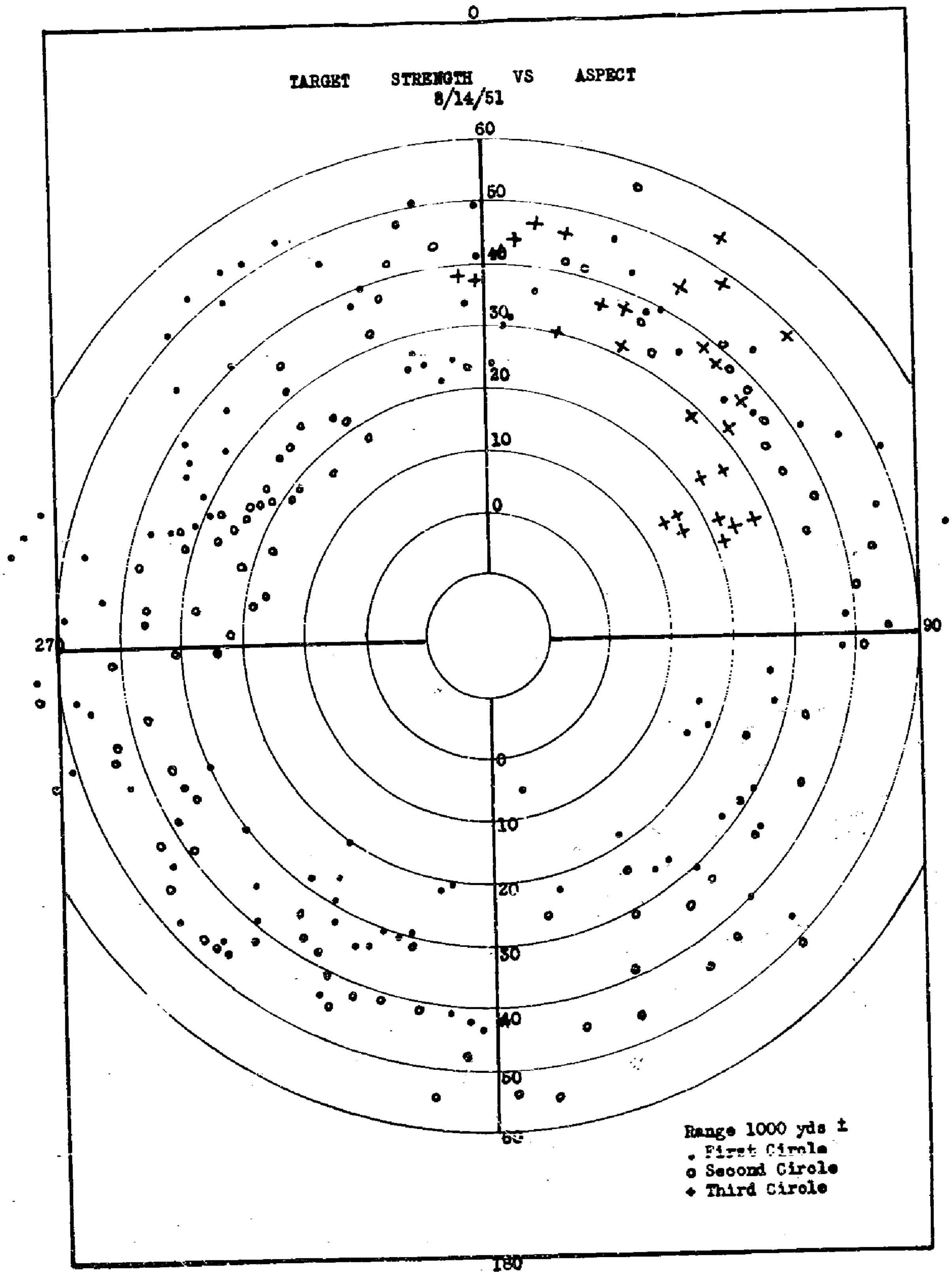

0
TARGET STRENGTH VS ASPECT
8/14/51
60
50
40
30
20
10
0
270
90
0
10
20
30
40
50
60
Range 1000 yds ±
. First Circle
o Second Circle
+ Third Circle
180

Figure 13

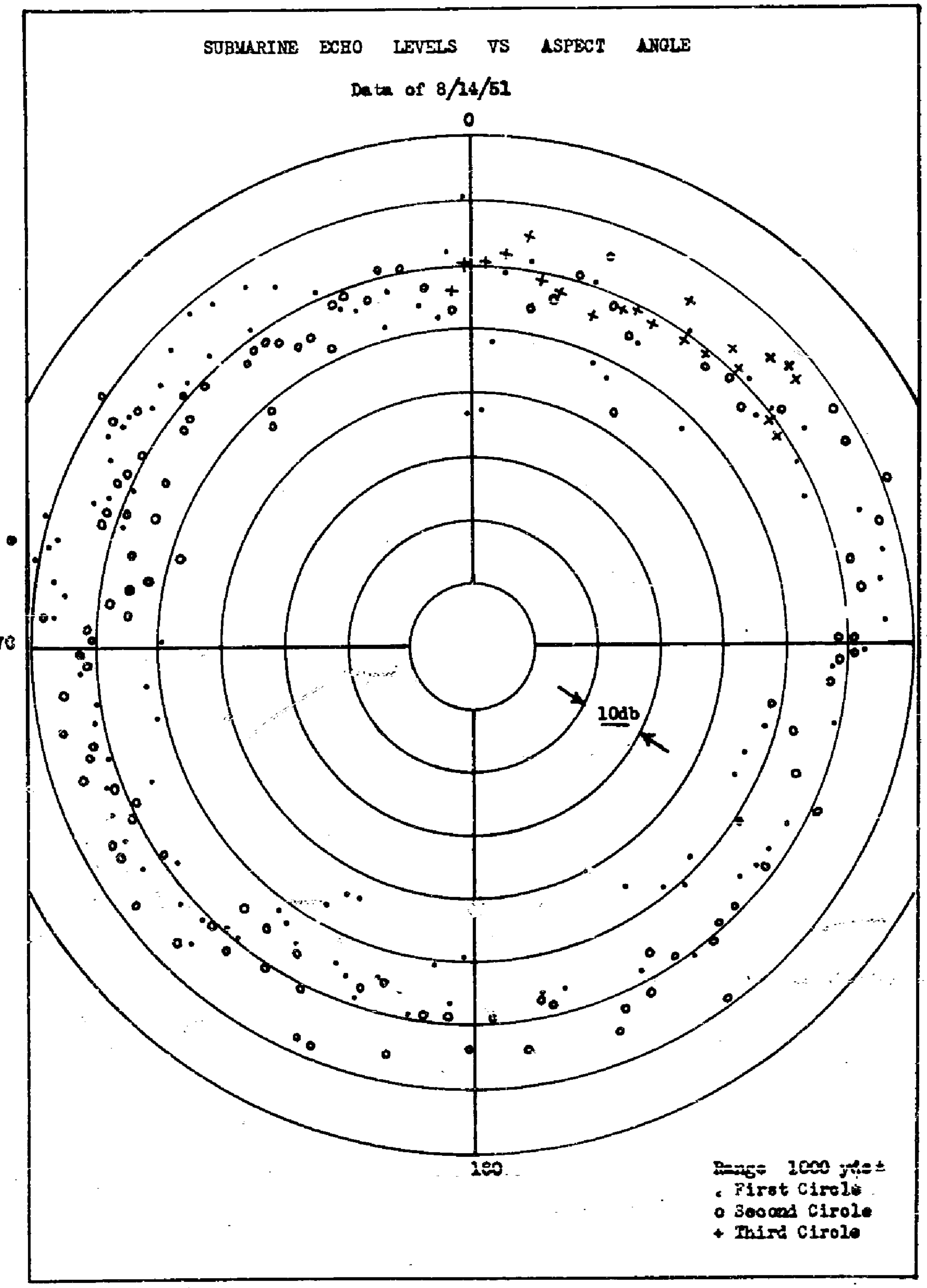

SUBMARINE ECHO LEVELS VS ASPECT ANGLE
Data of 8/14/51
0
90
180
270
10db
Range 1000 yds ±
. First Circle
o Second Circle
+ Third Circle

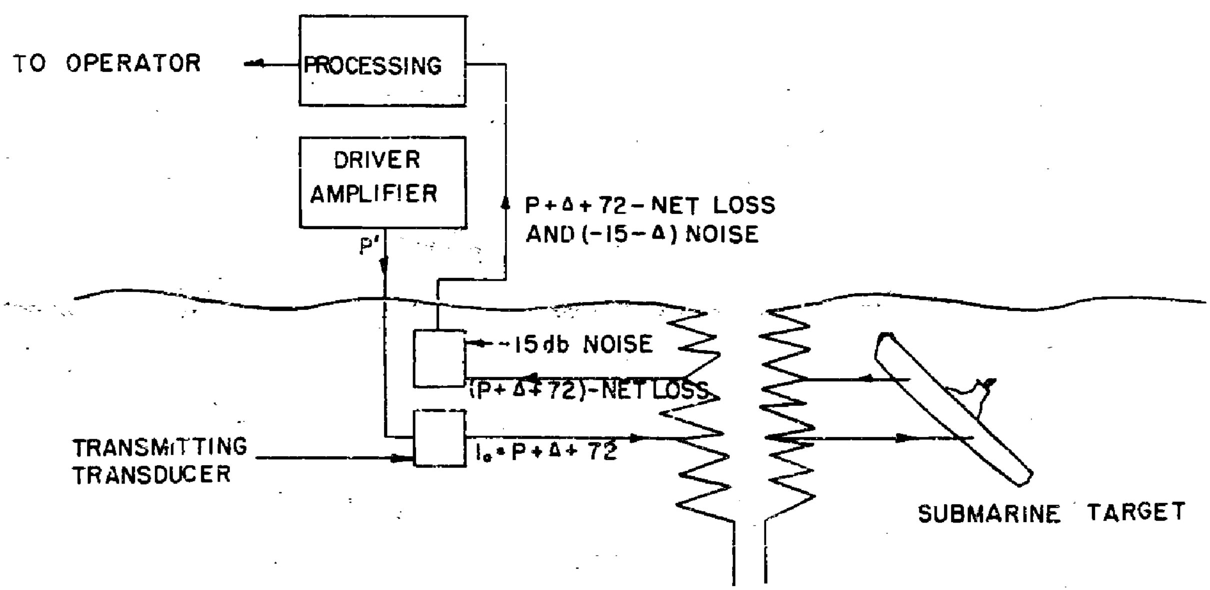
Figure 14

NET LOSS ON 10KC OVER THE ROUND TRIP

VIA THE BOTTOM

DEPTH	TILT	HORIZONTAL RANGE	PROPAGATION LOSS	REFLECTION LOSS	TARGET STRENGTH	NET LOSS
900 ft.	15°	13.5 Kyds.	194	22	32	184
1800 ft.	25°	15.5 Kyds.	203	22	32	193
2700 ft.	25°	23.2 Kyds.	227	22	32	217

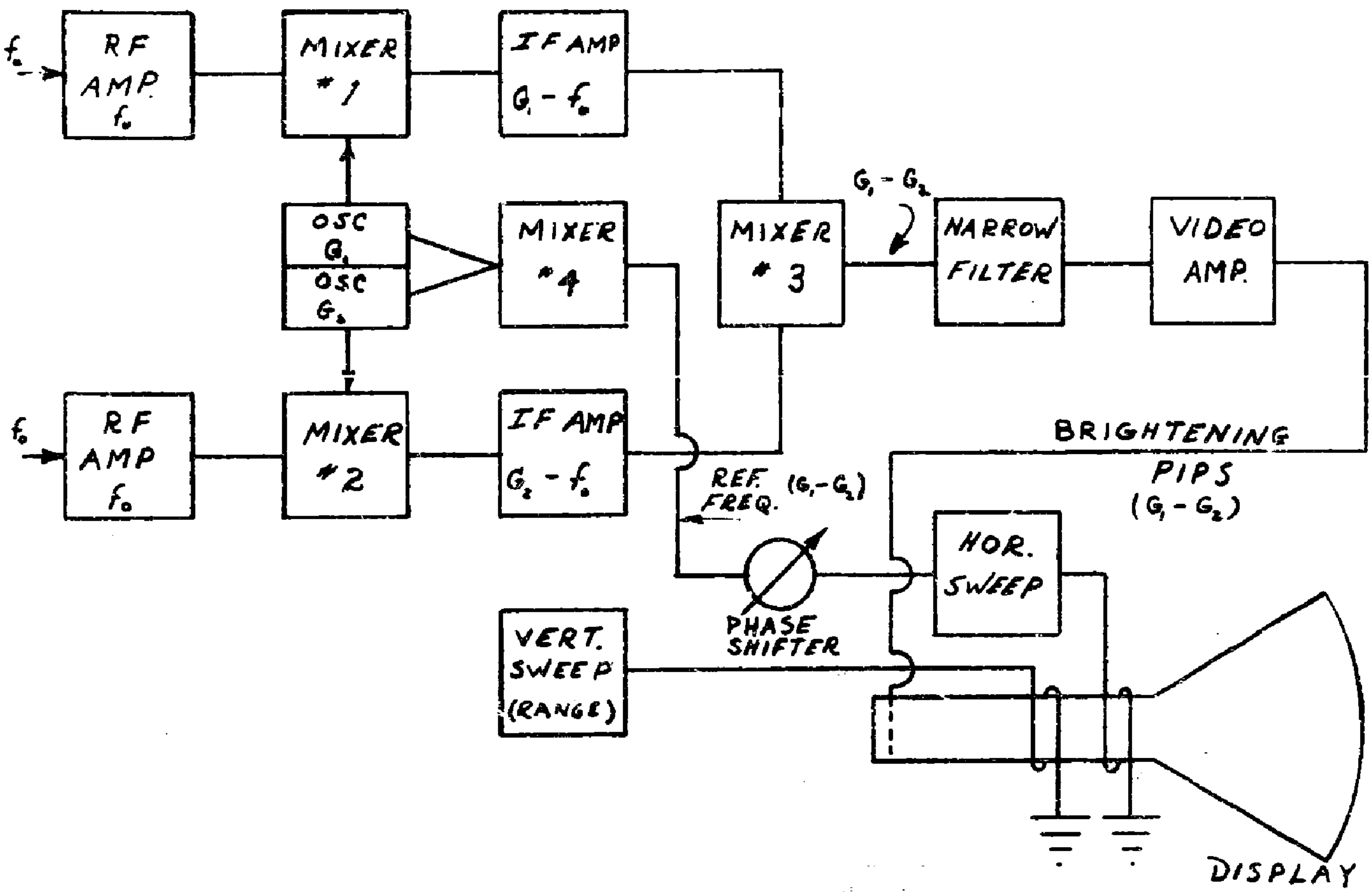
Figure 15



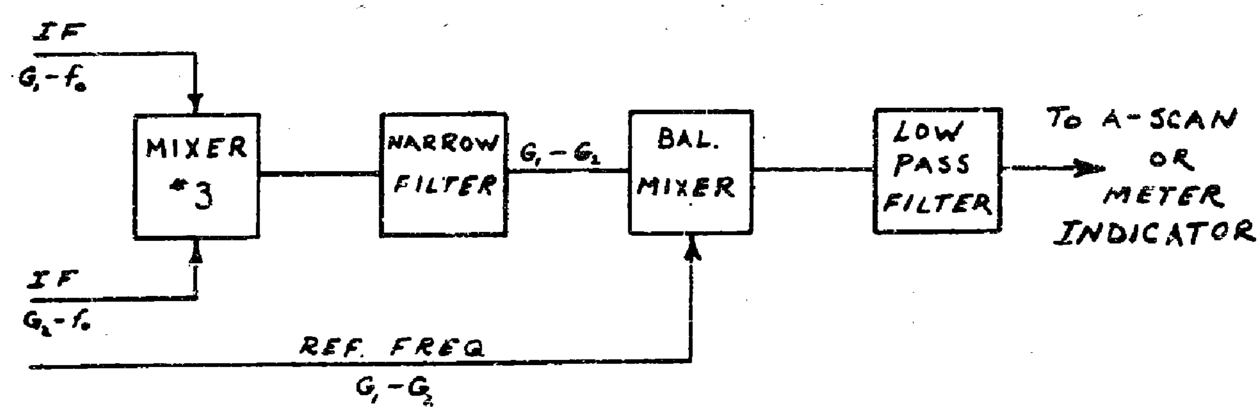
$(P+\Delta+72-\text{NET LOSS})-(-15-\Delta)=S$

$P+2\Delta-S=\text{NET LOSS}-87$ (97, 106, 130 db)

Figure 16



Block Diagram of Modified SSI



Block Diagram of Circuit for A-Scan

Figure 17

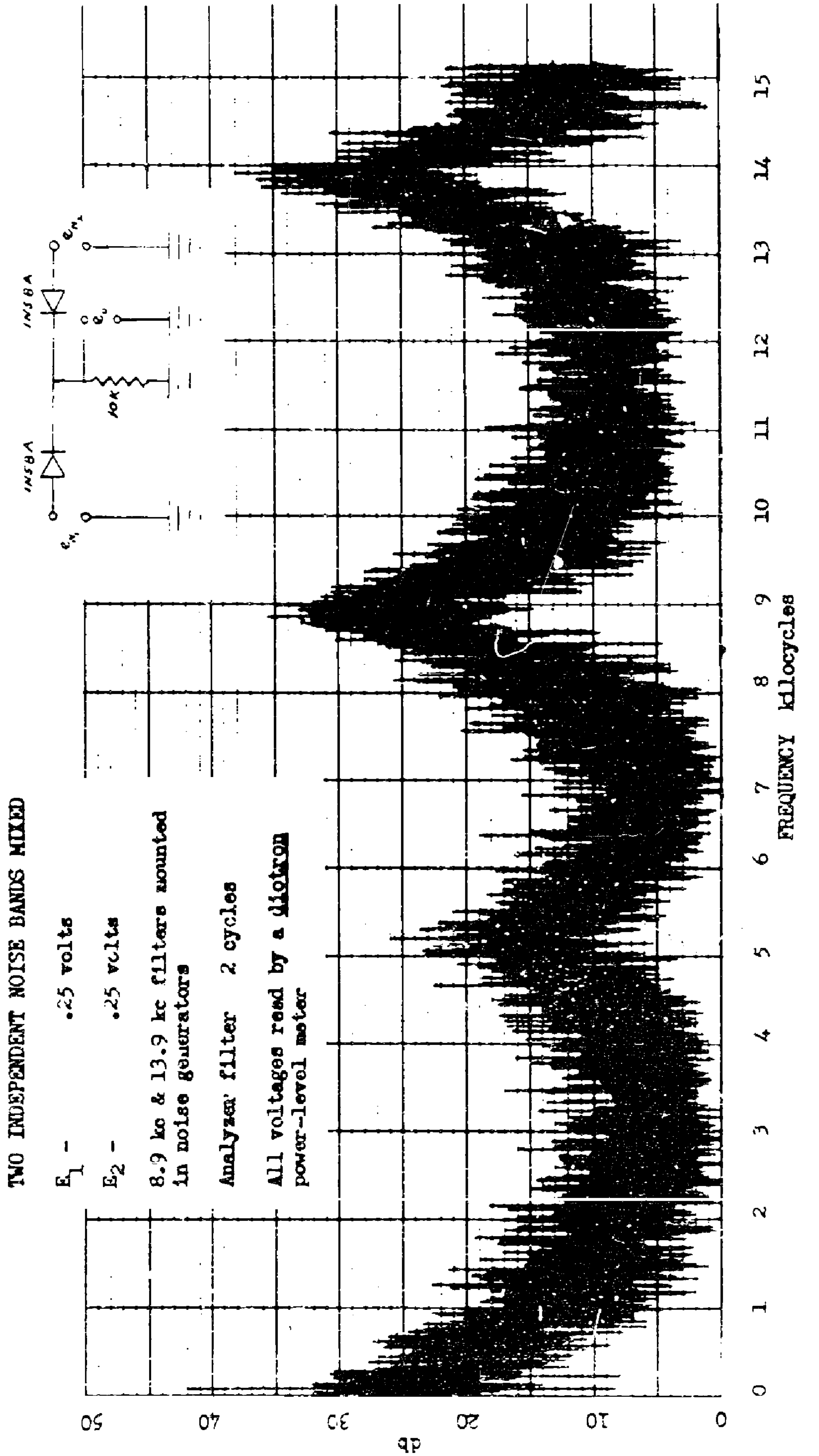

TWO INDEPENDENT NOISE BANDS MIXED
E1 - .25 volts
E2 - .25 volts
8.9 kc & 13.9 kc filters mounted in noise generators
Analyzer filter 2 cycles
All voltages read by a diotron power-level meter
INSBA
INSBA
10K
FREQUENCY kilocycles
db
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 10 20 30 40 50

Figure 18

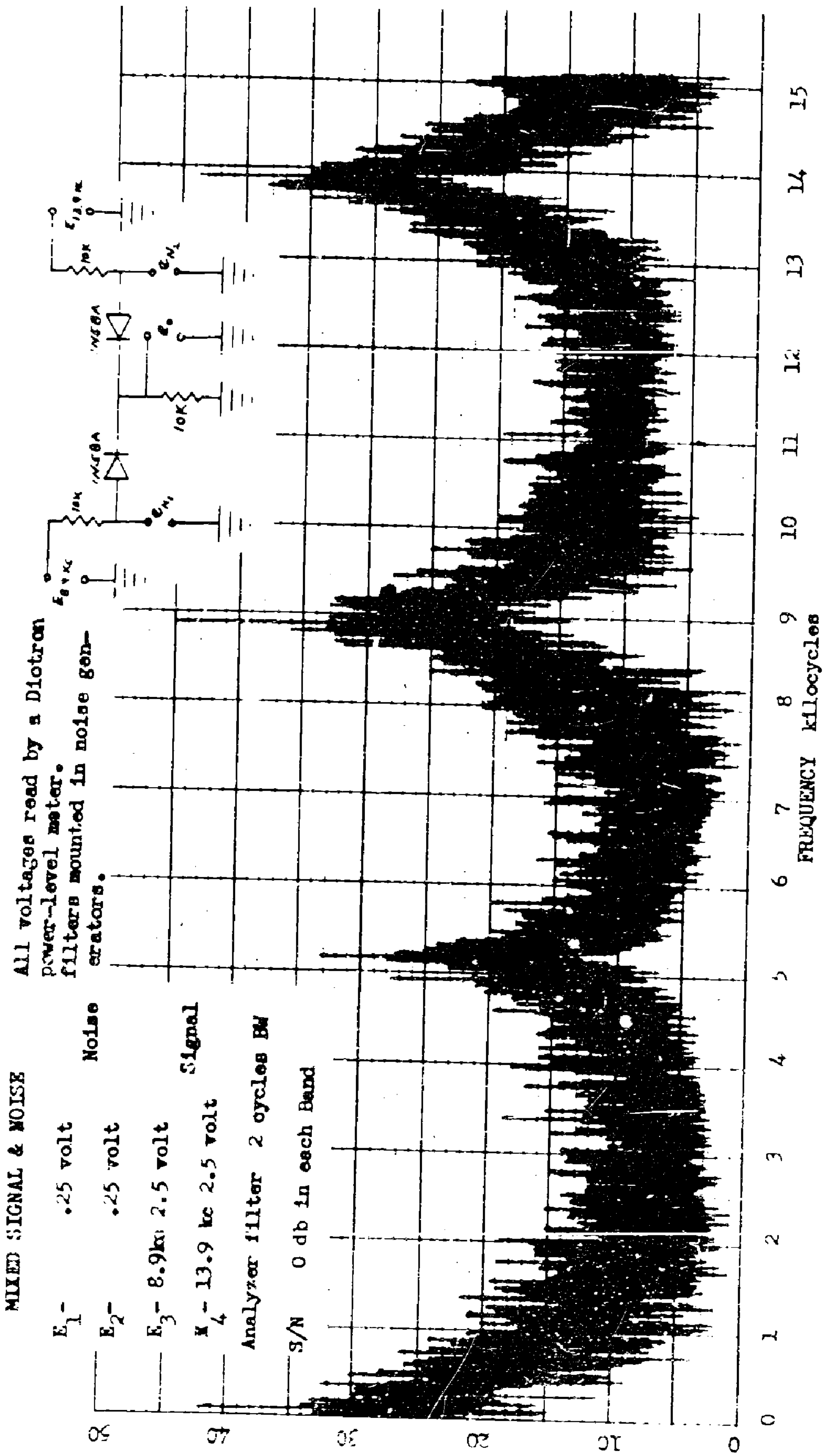

MIXED SIGNAL & NOISE
E_1 - .25 volt
E_2 - .25 volt
Noise
E_3 - 8.9kc 2.5 volt
E_4 - 13.9 kc 2.5 volt
Signal
Analyzer filter 2 cycles BW
S/N 0 db in each Band
All voltages read by a Diotron power-level meter. filters mounted in noise generators.
10K
1N48A
FREQUENCY kilocycles
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
db
0
10
20
30
40
50

Figure 19

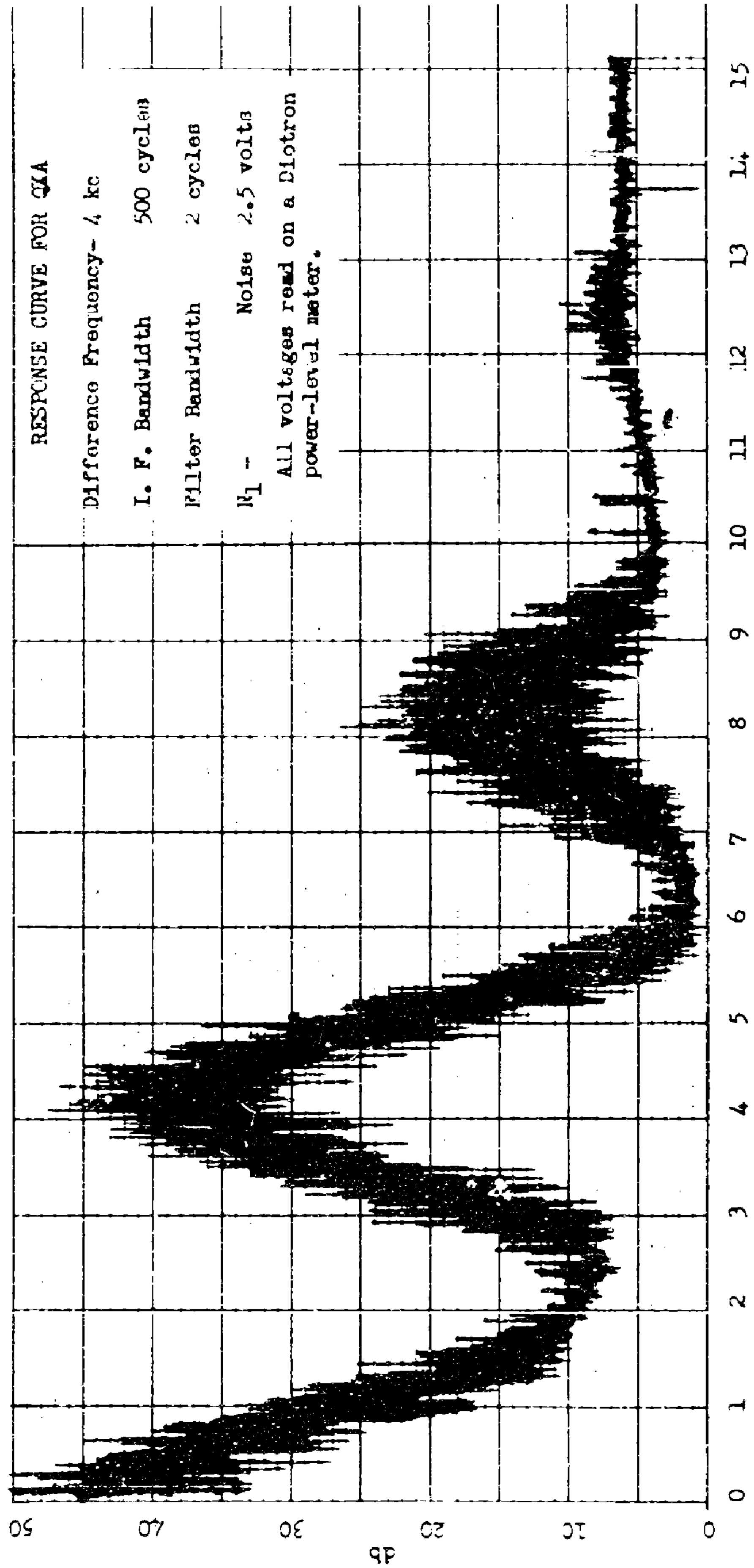
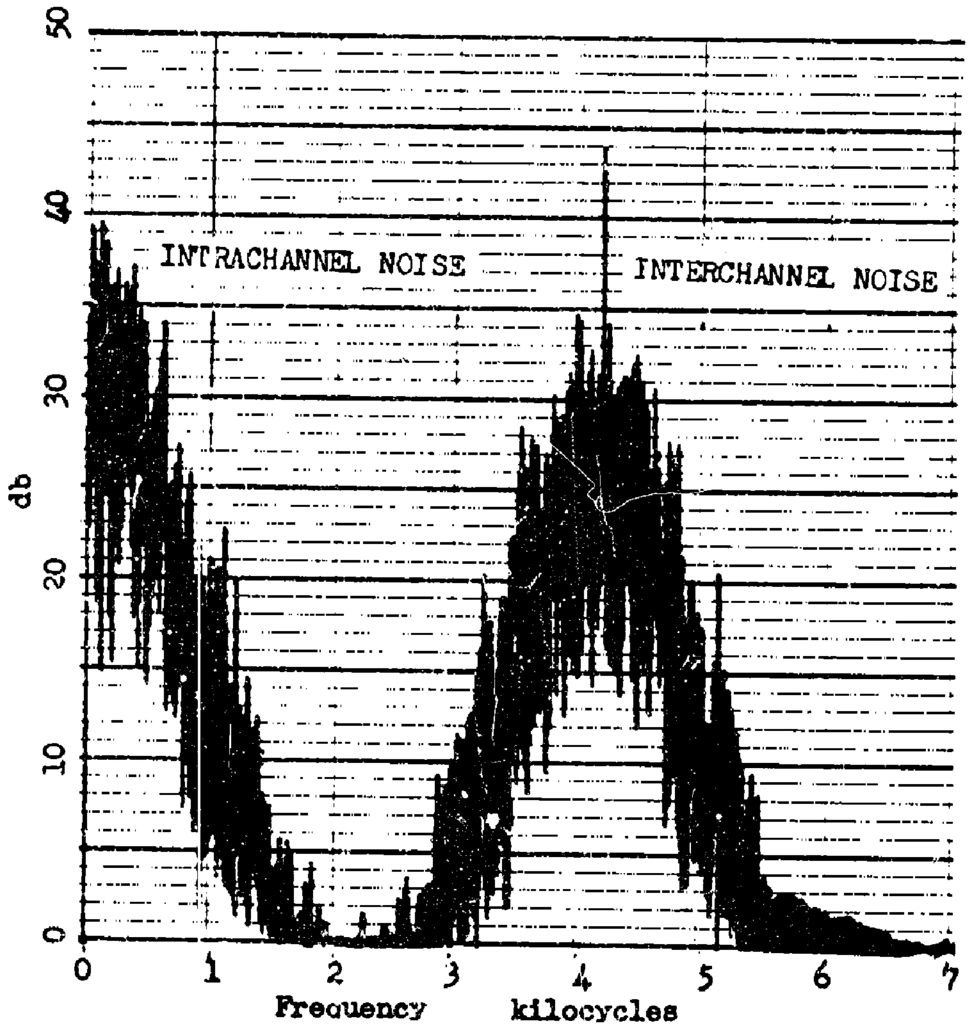

RESPONSE CURVE FOR QXA
Difference Frequency- 4 kc
I. F. Bandwidth 500 cycles
Filter Bandwidth 2 cycles
N_1 - Noise 2.5 volts
All voltages read on a Diotron power-level meter.
FREQUENCY kilocycles
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
db
0 10 20 30 40 50

Figure 20



RESPONSE CURVE FOR QXA

Difference Frequency - 4 kilocycles	
I. F. Bandwidth	500 cycles
Filter Bandwidth	2 cycles
N_1 - Coherent Noise	2.5 volts
N_2 - Incoherent Noise	2.5 volts
N_1/N_2	0 db

All voltages read on a Diotron power-level meter.

Figure 21

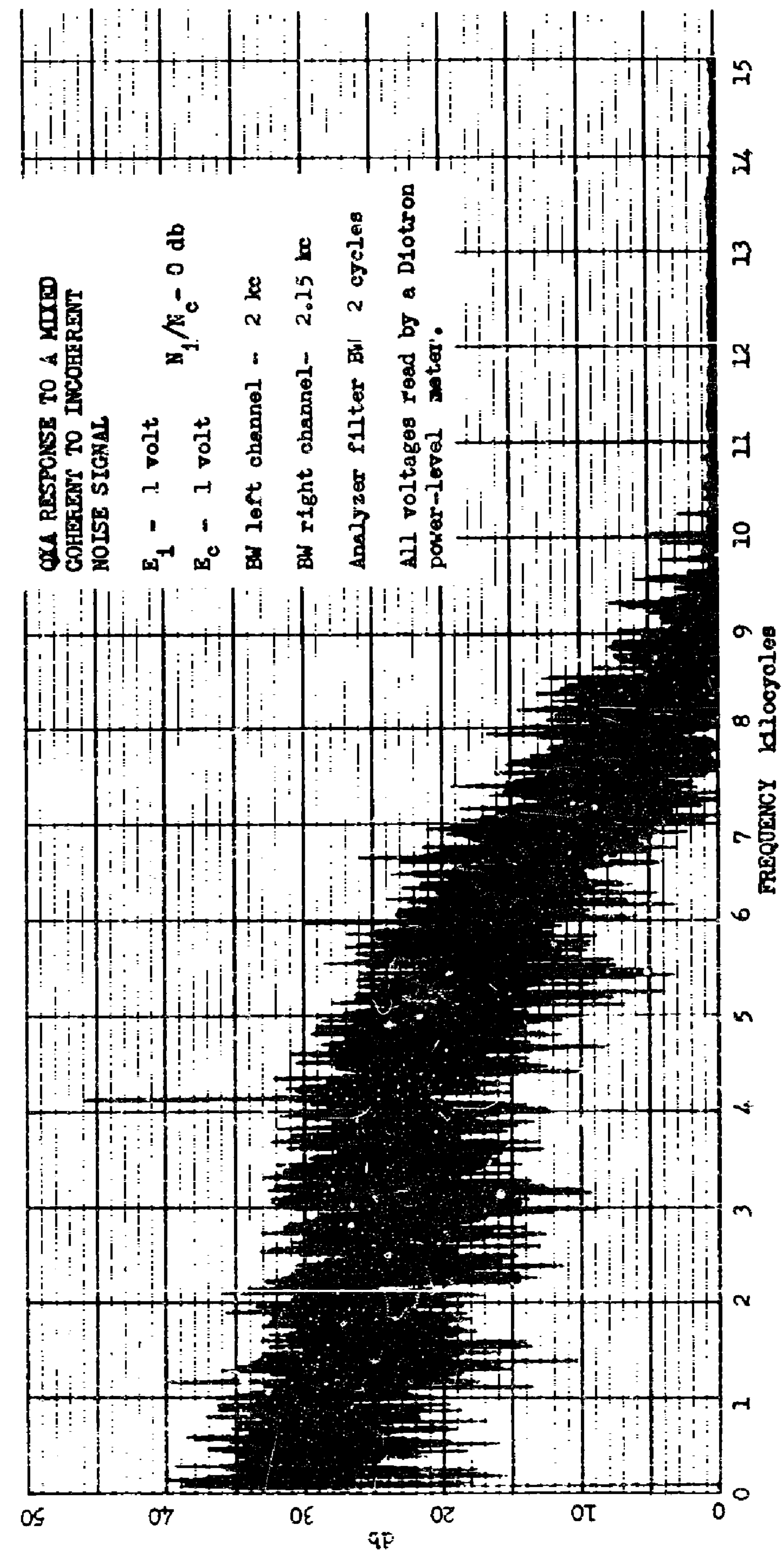

QXA RESPONSE TO A MIXED COHERENT TO INCOHERENT NOISE SIGNAL
E1 - 1 volt
N1/Nc - 0 db
Ec - 1 volt
BW left channel - 2 kc
BW right channel- 2.15 kc
Analyzer filter BW 2 cycles
All voltages read by a Diotron power-level meter.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
FREQUENCY kilocycles
0 10 20 30 40 50
db

Figure 22

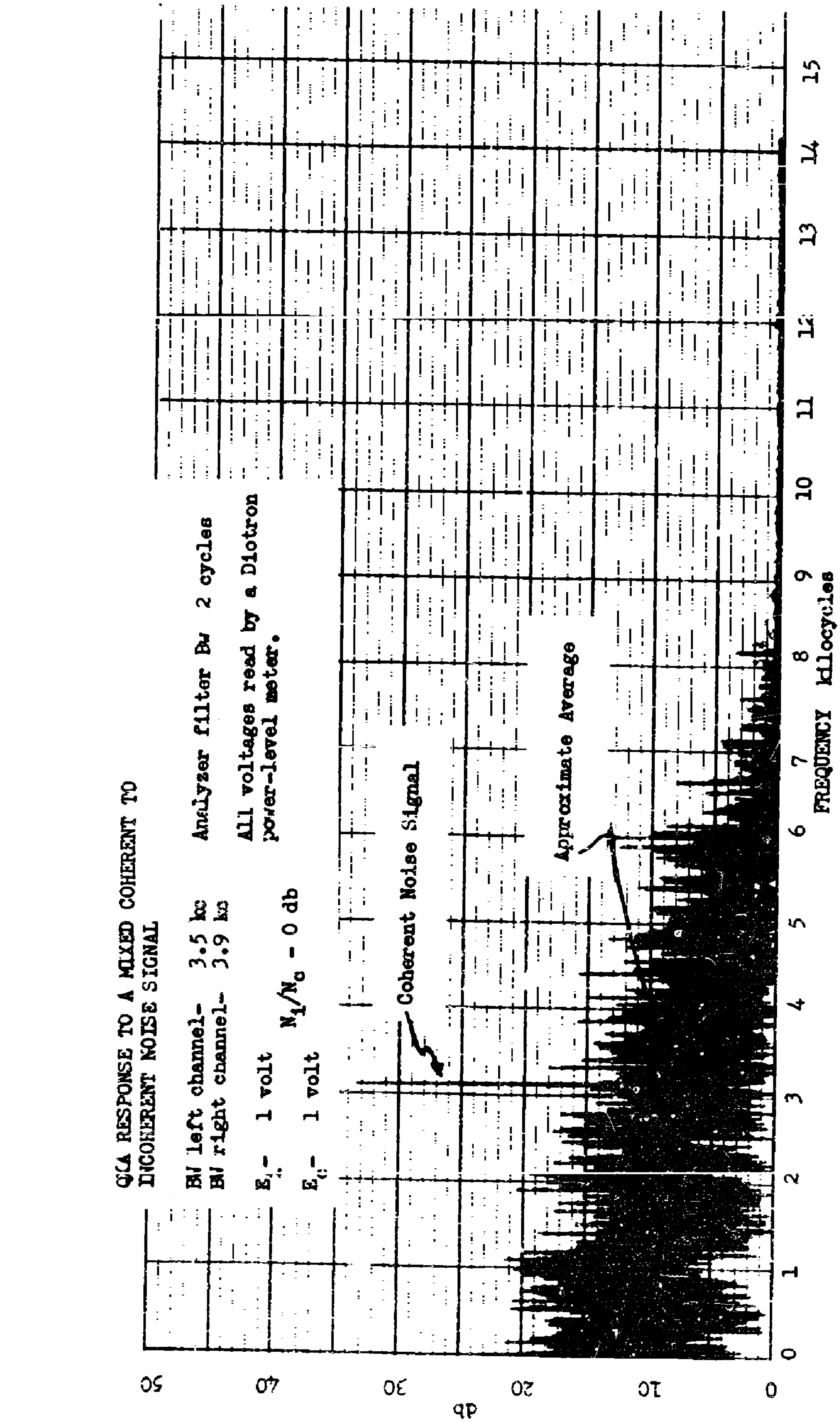

QCA RESPONSE TO A MIXED COHERENT TO
INCOHERENT NOISE SIGNAL
BW left channel- 3.5 kc
BW right channel- 3.9 kc
Analyzer filter Bw 2 cycles
All voltages read by a Diotron
power-level meter.
E_i - 1 volt
E_c - 1 volt
N_i/N_c - 0 db
Coherent Noise Signal
Approximate Average
FREQUENCY kilocycles
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
db
0 10 20 30 40 50

Figure 23

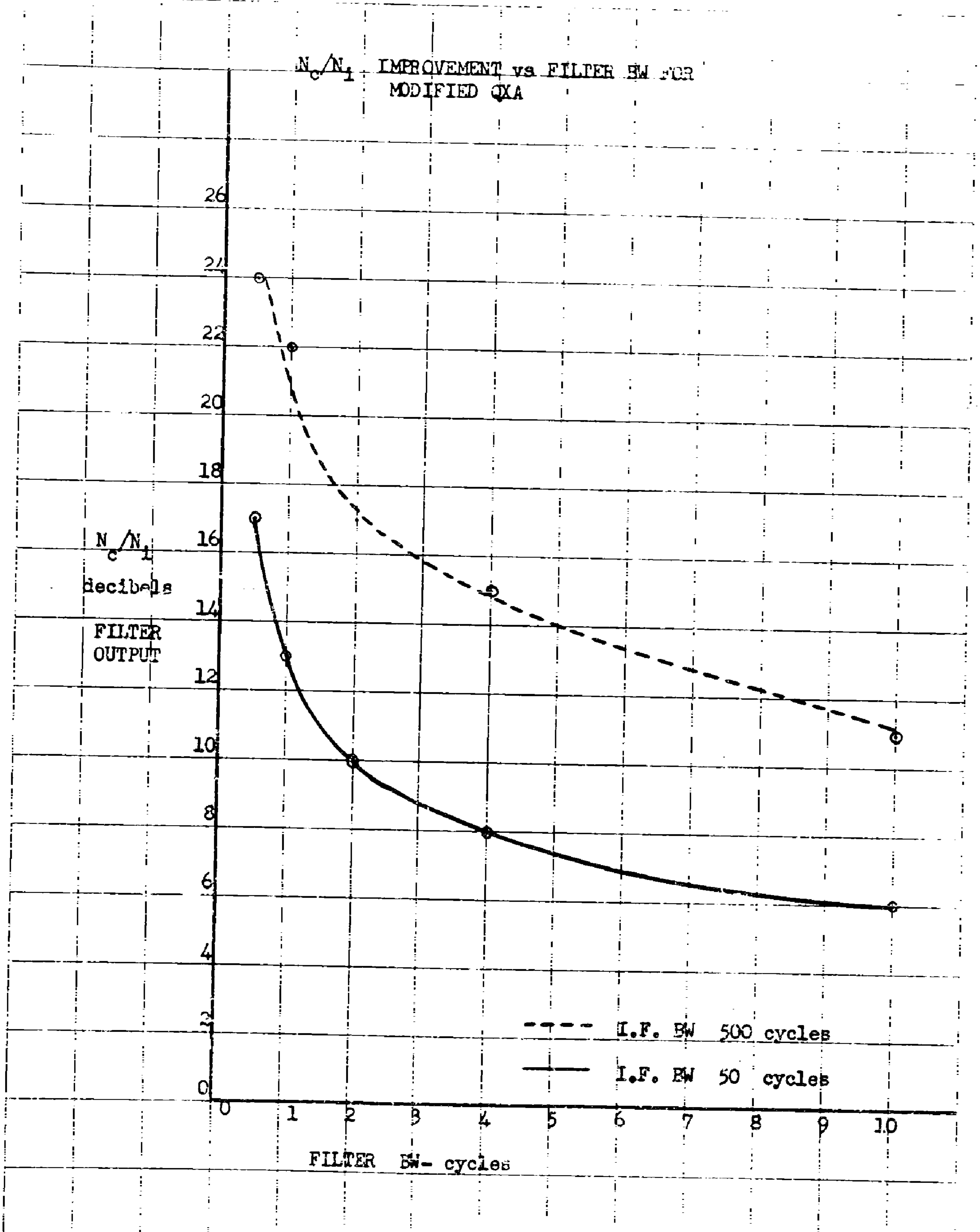

N_c/N_i IMPROVEMENT vs FILTER BW FOR MODIFIED QXA
N_c/N_i
decibels
FILTER OUTPUT
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
FILTER BW- cycles
I.F. BW 500 cycles
I.F. BW 50 cycles

Figure 24

10 KC LONG RANGE SONAR

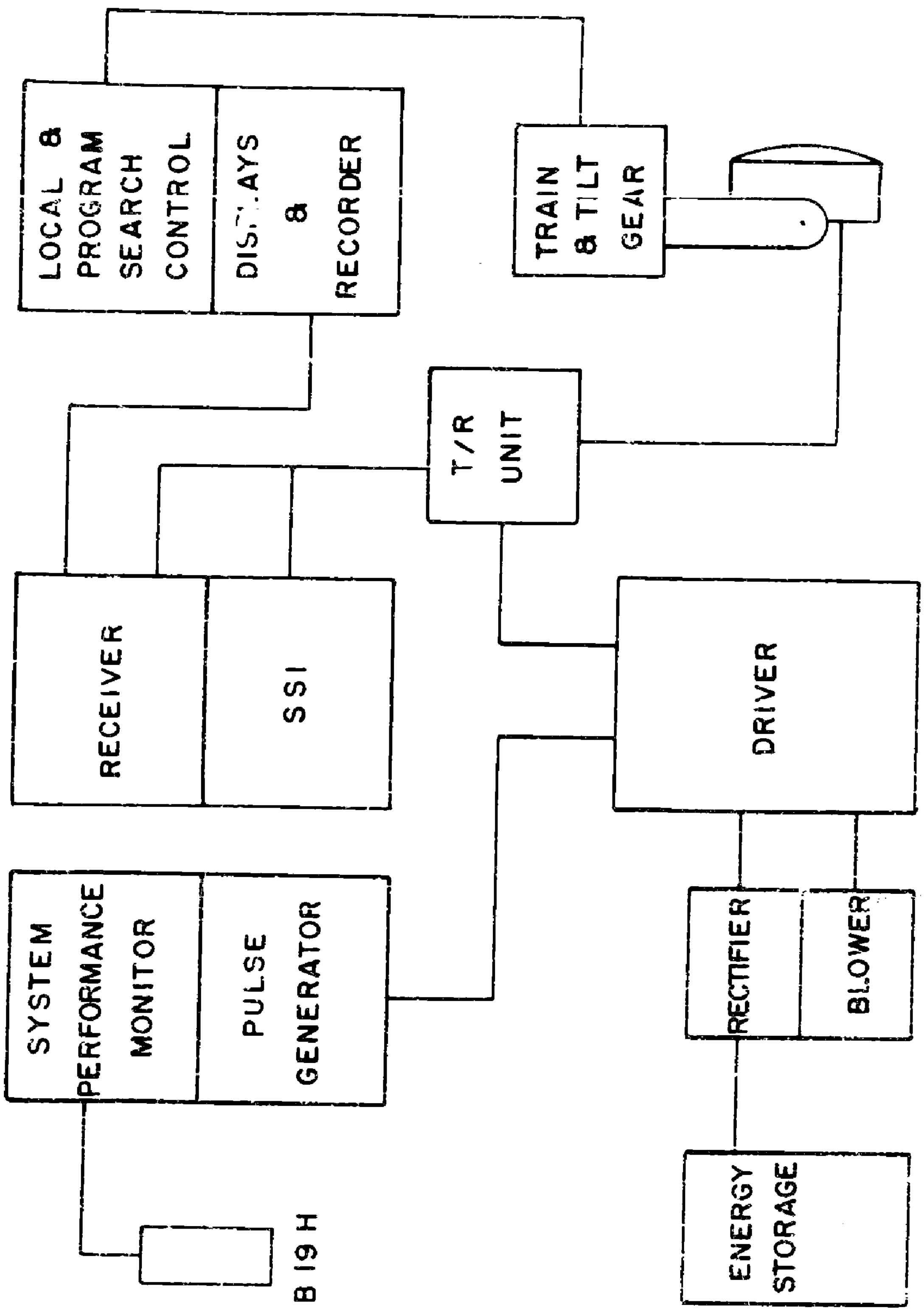


Figure 25

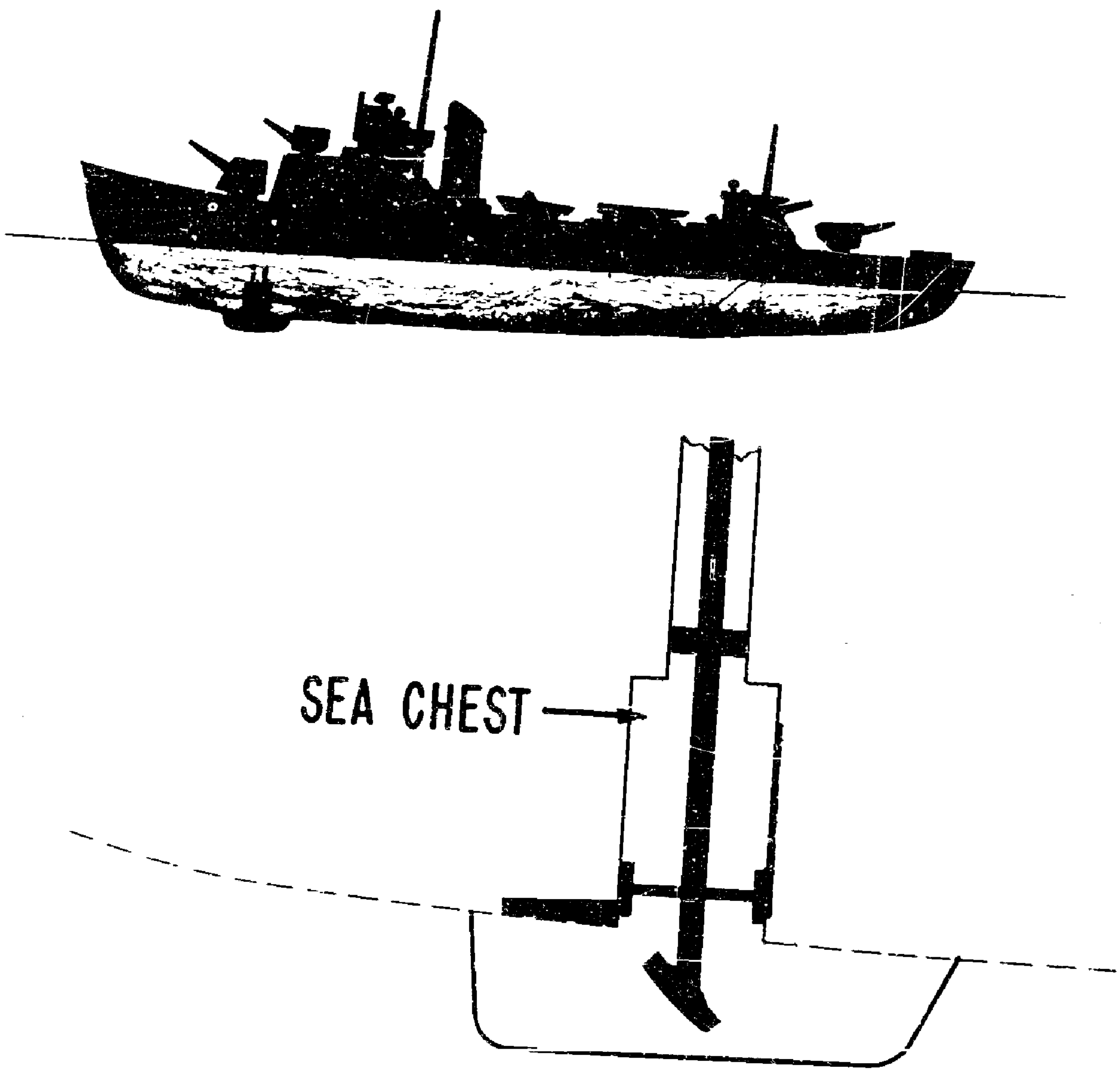


Figure 26

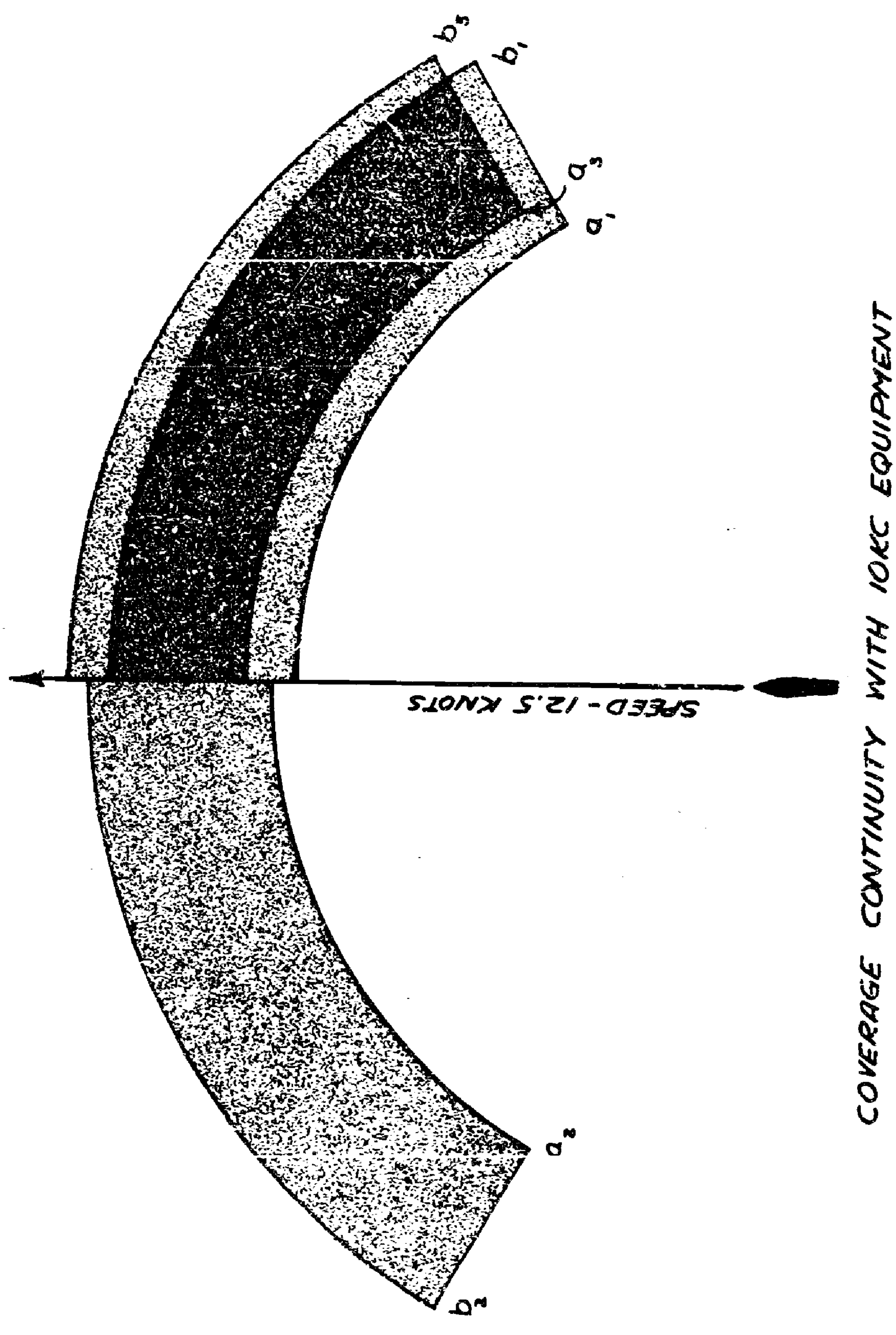
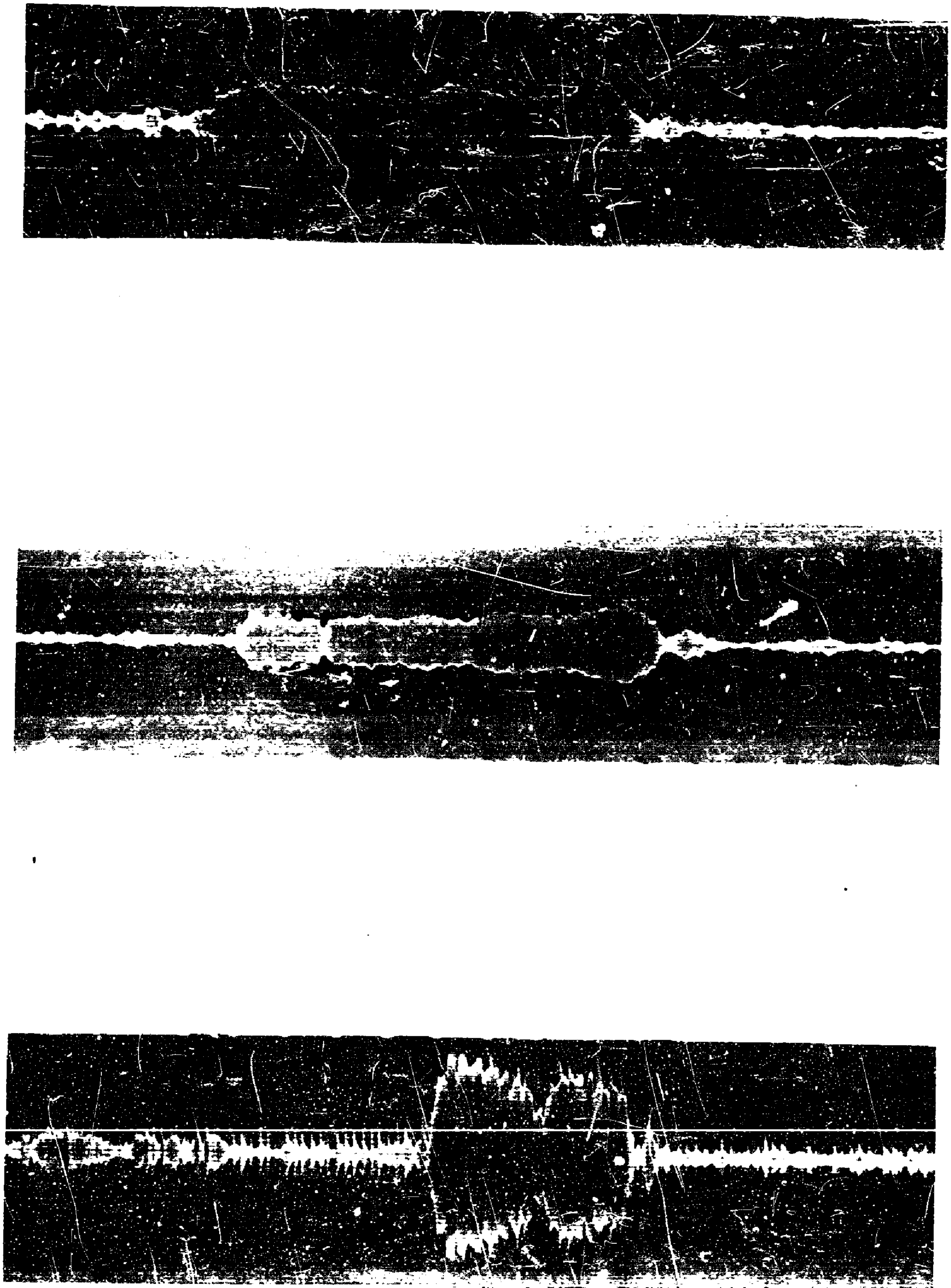
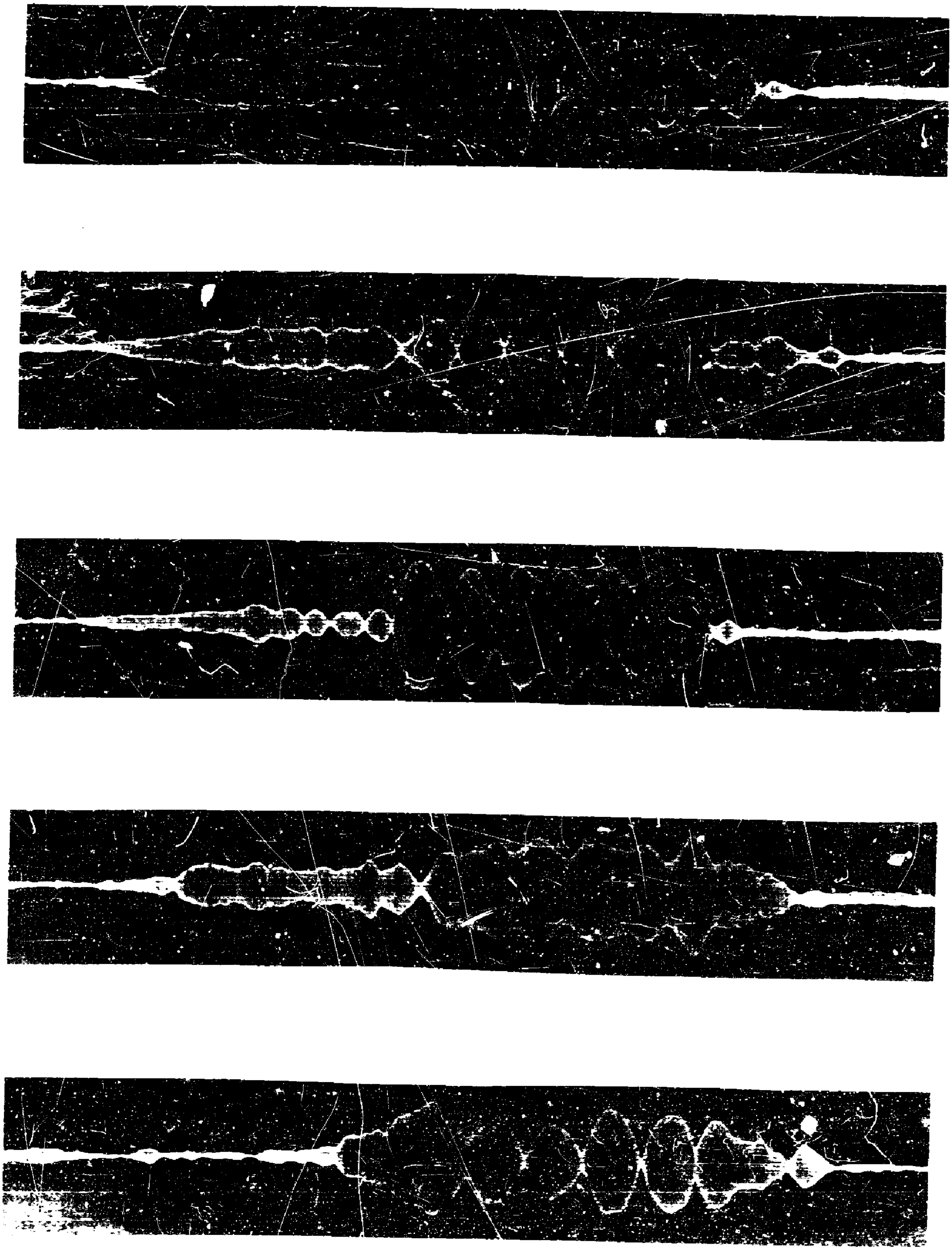

COVERAGE CONTINUITY WITH 10KC EQUIPMENT
8-30-51
SPEED - 12.5 KNOTS

Figure 27



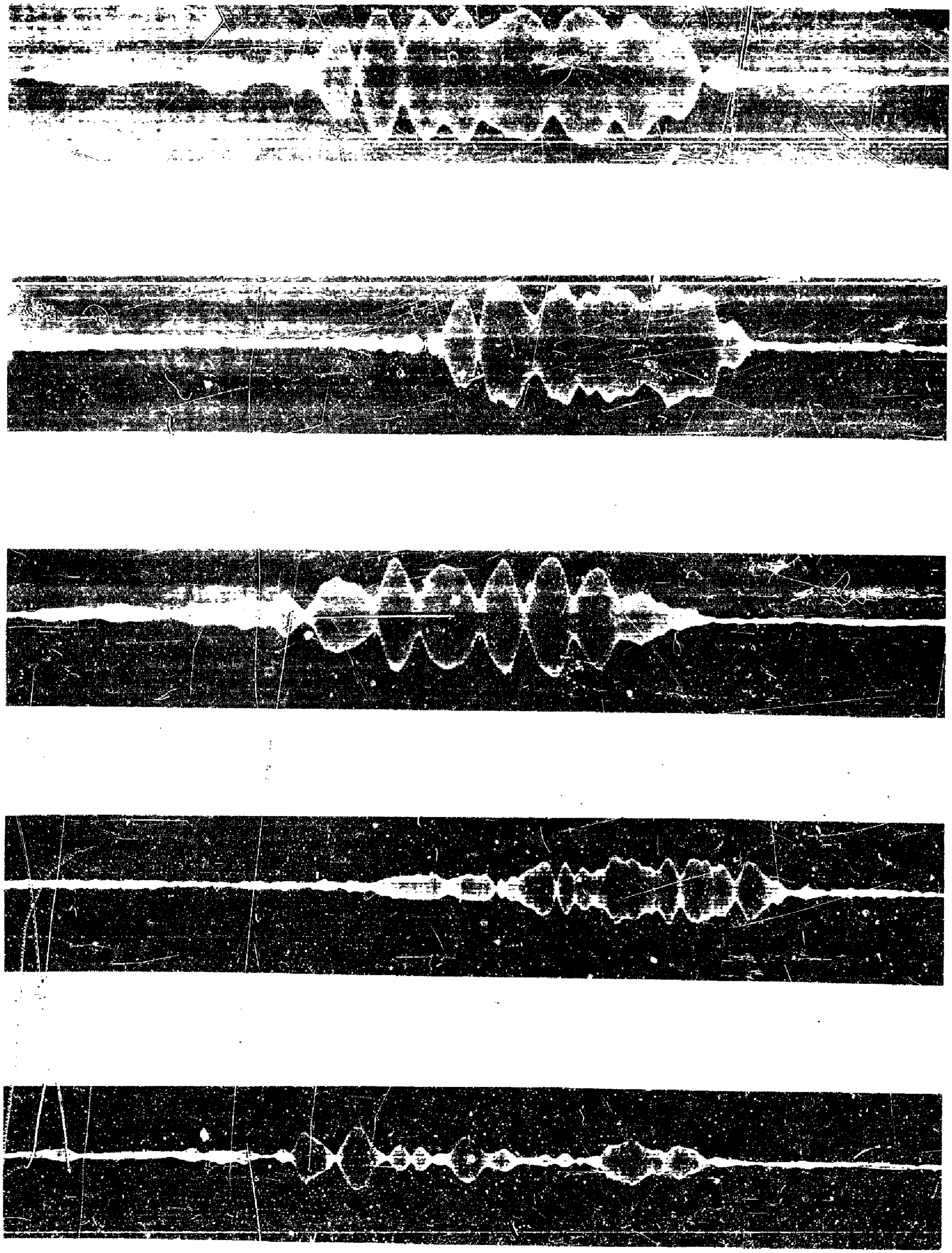
Submarine echoes - beam aspect

Figure 28



Submarine echoes - stern aspect

Figure 29



Submarine echoes - stern aspect

Figure 30

UNITED STATES GOVERNMENT

memorandum

7103/135

DATE: 19 November 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

VIA: Code 7100

REF: (a) NRL Confidential Report #3919 by H.L. Saxton et al, 28 Nov 1951 (U)

1. Reference (a) reports the proceedings of a symposium on long-range search sonar research held in support of active sonar reduction in operating frequency following World War II. The major frequency of sonars during World War II was 25 kHz. The research and development at NRL following the war progressed to 10 kHz, 5 kHz, and 2 kHz. This report consists of environmental and transmission loss measurements.

2. The technology and equipment of reference (a) have long been superseded. The current value of this report is historical.

3. It is recommended that reference (a) be declassified and released with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
Acoustics Division

CONCUR:

Edward R. Franchi

EDWARD R. FRANCHI Date
Superintendent
Acoustics Division

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OFFICE OF NAVAL RESEARCH, NAVAL RESEARCH LAB., WASH., D.C.
(NRL REPORT 3919)

LONG-RANGE SEARCH SONAR SYMPOSIUM OF SEPTEMBER 5, 1951

SAXTON, H.L.; URICK, R.J.; BAYSTON, T.E. AND OTHERS
28 NOV'51 56PP PHOTO, DIAGRS, GRAPHS, DRWGS

SONAR
ECHO RANGING

ELECTRONICS (3)
SONAR (14)

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*Sonar
Military App
Symposia